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RADIOLOGICAL SURVEILLANCE STUDIES AT THE OYSTER CREEK BWR NUCLEAR GENERATING STATION

OFFICE OF RADIATION PROGRAMS
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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RADIOLOGICAL SURVEILLANCE STUDIES AT THE OYSTER CREEK BWR NUCLEAR GENERATING STATION

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June 1976

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FOREWORD

The Office of Radiation Programs of the Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation and to promote development of controls necessary to protect public health and safety. In order to carry out these responsibilities relative to the nuclear power industry, the Environmental Protection Agency has performed field studies at nuclear power stations and related facilities. These field studies have required the development of means for identifying and quantifying radionuclides as well as the methodology for evaluating reactor plant discharge pathways and environmental transport.

Electrical generation utilizing light-water-cooled nuclear power reactors has experienced rapid growth in the United States. The growth of nuclear energy has been managed so that environmental contamination is minimal at the present time. The Environmental Protection Agency has engaged in studies at routinely operating nuclear power stations to provide an understanding of the radionuclides in reactor effluents, their subsequent fate in the environment, and the real or potential population exposures.

A previous study at the Dresden 1 reactor (210 MWe) provided an initial base for evaluating the environmental effects of operating boiling water reactors. This particular field study was performed at the Oyster Creek nuclear power station, a 640 MWe boiling water reactor. Results from this study have allowed the evaluation of the operational and environmental effects of larger boiling water reactors, and will provide a better basis on which to evaluate larger reactors not yet operating. This is the last in a series of four studies which also included the Yankee Rowe (185 MWe) and Haddam Neck (573 MWe) pressurized water reactors. The Oyster Creek study was the only one in the series directed at environmental impacts in a salt water coast environment.

Comments on this report would be appreciated. These should be sent to the Director, Technology Assessment Division of the Office of Radiation Programs, Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

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1. INTRODUCTION

1.1 Need for Study

Radiological monitoring is an integral part of routine operation at a nuclear power station. Radionuclides in discharges and direct radiation at the station are measured to demonstrate compliance with operating regulations and to compute the population exposure with radiation exposure models. Measurements of radionuclides and radiation in the environment can check the models, yield the radionuclide transfer or dispersion factors most appropriate to the site, and assure that population exposures are within established limits.

Unless the environmental surveillance program is carefully planned in terms of the models with regard to critical radionuclides, pathways, and exposed populations, much of it will be uninformative and result in a large number of inappropriate "less-than" values. An effective program uses the results of on-site measurements to select sample types, locations, collection times, and amounts, as well as procedures and instruments for the analyses. To provide guidance for applying these on-site and environmental measurements to evaluate population radiation exposures, the Office of Radiation Programs (ORP) of the U.S. Environmental Protection Agency (EPA) undertook a program of studies at commercially operated nuclear power stations. The Nuclear Regulatory Commission (NRC), the Energy Research and Development Administration (ERDA), state health or environmental protection agencies, and station operators have participated in these studies. This report describes the fourth and final project in this series of studies — two at pressurized water reactors (PWR's) and two at boiling water reactors (BWR's). Results of the first three projects, at the Dresden I BWR, the Yankee-Rowe PWR and the Haddam Neck PWR, have been published.*(1–3)*

Guidance for evaluating population radiation exposures by emphasizing the observation of critical radionuclides, pathways, and exposed populations in the environment has been available for some time.*(4)* This approach concentrates efforts on the few most important ("critical") causes of exposure in the presence of many potential ones. Models for computing radionuclide transfers — for example, from water to fish, stack to vegetation, stack to cows' milk for ^{131}I, and stack direct to man — have been utilized in the earlier reports,*(1–3)* and are described fully in the AEC, NRC and EPA models.*(5–7)* During the last few years, considerable information has been published concerning the movement and transfer of radionuclides in the environment at nuclear facilities,*(8–16)* as well as additional guides for environmental monitoring. *(17–18)* There are also at least two additional reports available describing environmental studies at commercial nuclear power stations in the U. S.*(19,20)*

The four stations were selected for study so as to provide generally applicable information. Because the program was begun during the initial expansion in nuclear power production, the first two stations studied at Dresden and Yankee-Rowe were relatively small while the third and fourth were at the larger Haddam Neck and Oyster Creek stations. Hence, care must be taken in applying observations at these stations to larger or newer stations that are different in design and operation. Oyster Creek was selected for study in part because it included a marine environment, whereas, the three previous stations studied were sited on bodies of fresh water. The study was planned to contribute information specific to large BWR stations on the radionuclide content of effluents, their sources and pathways, evaluation of population radiation exposures, techniques of measuring radionuclides and radiations at the station and in its environment, and provide additional guidance on environmental monitoring.

1.2 The Station

The study was undertaken at the Oyster Creek Nuclear Generating Station, a direct cycle BWR manufactured by the General Electric Company for the Jersey Central Power and Light Company. The station began operating in 1969 and reached its present maximum power level of 1930 megawatts thermal (MWt)in 1971; the corresponding gross electrical output is approximately 640 MWe. The station had produced more than 16 million megawatt hours (1.84

GW-yr) of electricity at the end of 1973. Operation of the station is described in several publications.*(21–24)*

During the study, the reactor was partially refueled twice — in September 1971 and May 1972. The fuel elements consist of uranium dioxide (UO_2) pellets enriched to 2.42% in ^{235}U, enclosed in annealed Zircaloy-2 tubes.*(21,22)* Water serves as both moderator and coolant.

The station is located in a relatively flat marshland area of Ocean County, New Jersey, about 3.2 km inland from the shore of Barnegat Bay. The site is situated 14.5 km south of Toms River, New Jersey and 56 km north of Atlantic City, New Jersey. It is bounded on the east by the Central Railroad of New Jersey and U.S. Route 9; on the west by the Garden State Parkway; on the north by the South Branch of Forked River and on the south by Oyster Creek.*(22)*

The study was undertaken at Oyster Creek because it was one of only two large BWR stations — the other was Nine Mile Point — in the U. S. that had been operating for more than a year in 1971. For comparison, the commercial BWR stations that had been operated for a full year in 1973 are listed in Table 1.1 with their radioactive discharges in curies (Ci) during that year.*(24)* All of the stations listed in Table 1.1 contain reactors manufactured by the General Electric Company. The gross radioactivity at Oyster Creek in both liquid and airborne waste is shown by Table 1.1 to have been similar to values at other stations. The relatively high amounts of ^{131}I released at Oyster Creek reflected in the last column is attributed to fission produced ^{131}I leaking through the fuel cladding. The very low radioactivity in liquid waste released at Monticello is due to their recycle of processed wastes and the shipment of laundry off-site, resulting in a near-zero release to the environment.

1.3 The Study

Field trips to the station and its environs were conducted between October 1971 and November 1973, scheduled to observe radionuclide concentrations throughout the station operating cycle and in the environment at various seasons. Because liquid effluents were discharged into a marine environment abundant with aquatic life, often utilized as food, the aquatic portion of this study was greatly expanded relative to the previous three studies. Measurements were considered to approximate average or total radionuclide values for sources and pathways sufficient for the generic purpose of the study. The computed averages or totals from this study are compared, when possible, with values obtained on a more frequent basis by the station operator to evaluate the applicability of the measurements during the field trips. The field trips were not intended to be inspections of operating practices at the station.

Table 1.1 Operating Data on Selected BWR Nuclear Power Stations, 1973

Station	Year of initial operation	Rated power, MWe	1973 power generation, 10^6 MWt-hr	Liquid waste, Ci		Airborne waste, Ci	
				MFP* & activation products	^3H	Gases	Particulates & Halogens**
Dresden I	1959	200	2.4	9.2	19	8.4×10^5	0.3
Millstone I	1970	652	6.0	33.4	4	0.8×10^5	0.2
Vermont Yankee	1972	514	6.1	2×10^{-5}	0.1	1.8×10^5	0.1
Monticello	1970	545	9.9	0†	0†	8.7×10^5	6.5
Nine Mile Point	1969	625	11	40.8	47	8.7×10^5	5.9
Oyster Creek	1969	640	11	2.4	36	8.1×10^5	30.7
Pilgrim I	1972	664	13	0.9	0.4	2.3×10^5	8.2
Dresden 2, 3	1970/71	809 ea.	27	25.9	26	8.8×10^5	27.0
Quad Cities 1, 2	1971/72	800 ea.	31	21.4	25	9.0×10^5	12.5

* MFP - Mixed fission products.

**All halogens are included.

† No liquid release.

The Radiochemistry and Nuclear Engineering Facility at the EPA National Environmental Research Center, Cincinnati, performed the study with the support of the Technology Assessment Division, ORP-EPA, and other EPA laboratories. Cooperating in these studies were the persons listed in Appendix A from the New Jersey Department of Environmental Protection, the Health and Safety Laboratory, ERDA, the Health Services Laboratory, ERDA, the U.S. Coast Guard Station at Floyd Bennett Field, New York, the Jersey Central Power and Light Co., the ERDA and the NRC.

The study was planned on the basis of results obtained at the similar but smaller BWR station at Dresden-I.*(1)* In addition, the following information provided guidance: publications describing the Oyster Creek station and environment,*(22,23,25–28)* semi-annual station operating reports, and the state's environmental surveillance reports.*(29,30)*

This information suggested that:

1. several sources at the station emit gaseous and liquid effluents of possible dosimetric import; however, the off-gas from the steam condenser air ejectors and the liquid from the test tanks would probably be the major sources;
2. critical radiation exposure pathways probably include fish and clams caught in Oyster Creek and in Barnegat Bay near the mouth of Oyster Creek, external radiation from effluent gases, and direct radiation from the plant;
3. bottom sediments in Oyster Creek and aquatic vegetation and macro-algae in Oyster Creek and Barnegat Bay would contain readily detectable radionuclides from the station;
4. radioiodine might be at detectable levels in the thyroid of cattle, if any grazed near the station;
5. dilution factors for radionuclides in Barnegat Bay would be difficult to calculate due to the complex hydrology of the Bay.

The measurement program accordingly emphasized these aspects of the station and its environment. It differed from previous station studies with respect to (1) terrestrial sampling was minimal because of the state's thorough environmental sampling program and sparse sampling media, and (2) most in-plant sampling was conducted by the AEC.*(31)*

1.4 References

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2. RADIONUCLIDES IN WATER ON SITE

2.1 Water Systems and Samples

2.1.1 *General.* The power-producing systems at Oyster Creek are, in general, typical of BWR's. Water flow pathways in the reactor coolant systems are shown in Figure 2.1.*(1)* Other water systems on site include reactor cleanup and demineralizer, circulating water, standby core cooling, primary containment spray cooling, standby liquid control, fire protection, makeup water, service water, reactor building closed cooling water, turbine building closed cooling water, fuel storage pool filtering, demineralizing and cooling, and sewage treatment. Plant electrical production and periods of operation are indicated on Figure 2.2.*(2)*

2.1.2 *Reactor coolant system.(3)* The reactor at Oyster Creek is a direct-cycle BWR. During routine operation, feed water at 150° C and 1000 psig enters the reactor vessel through the feedwater nozzle and is mixed with recirculating water. A mixture of steam and water is generated as the reactor coolant passes upward through the reactor core and is heated by fissioning in the nuclear fuel. At this stage the water-steam mixture is considered "low-quality" steam. The excess entrained water is removed by steam separators located in the reactor vessel directly above the core and the steam is then dried in a steam dryer assembly above the steam separators. The dry steam at 285° C and 950 psi flows to the turbines at a rate of 900 kg/s (7 x 10^6 lb/hr). Approximately 2.0 x 10^5 kg of water plus 6 x 10^3 kg of steam are in the reactor coolant system.*(4)*

Water removed in the steam separators is returned to the main recirculation flow within the vessel and is pumped through the five recirculation loops. Flow rate through the recirculation loops is varied to control reactor power. When the reactor is operating at rated power, rapid power maneuvers can be accomplished by

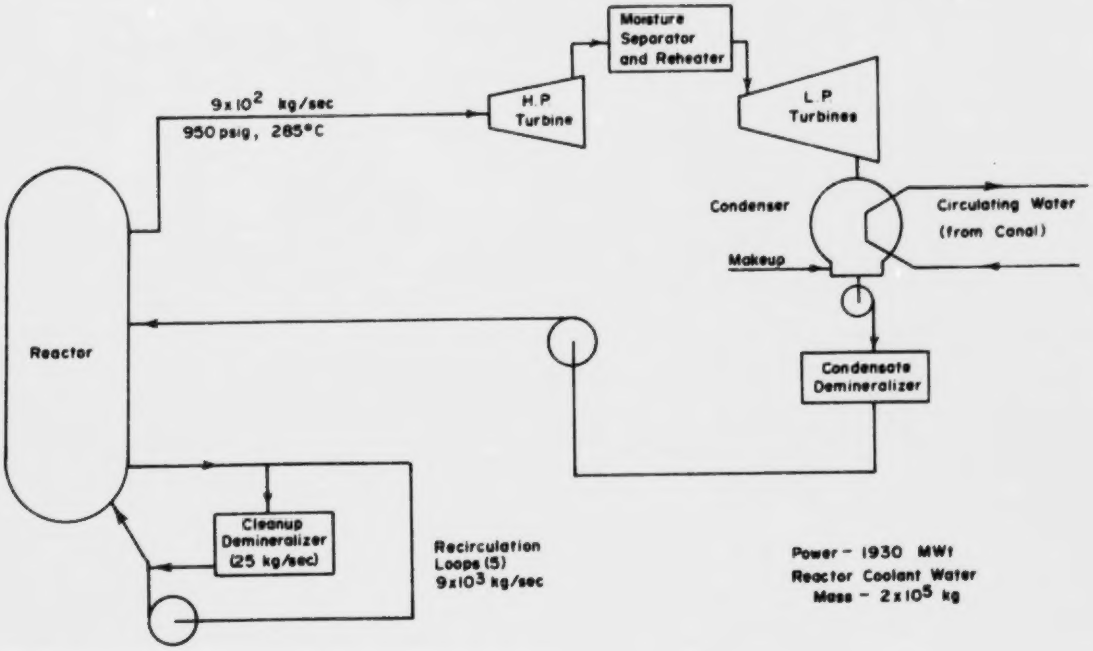
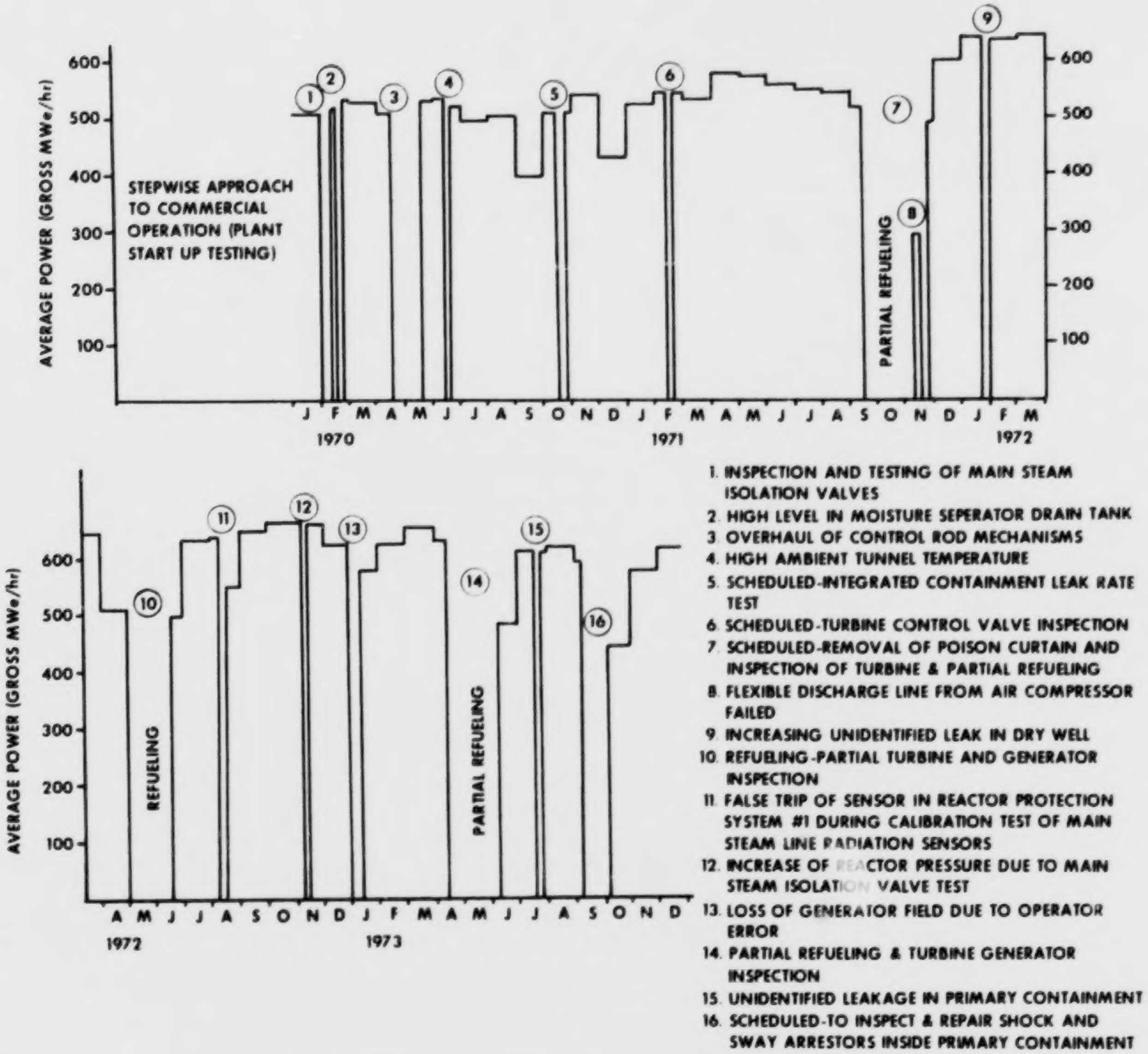

Moisture Separator and Reheater
9x10² kg/sec
950 psig, 285°C
H.P Turbine
L.P Turbines
Condenser
Circulating Water (from Canal)
Makeup
Reactor
Condensate Demineralizer
Cleanup Demineralizer (25 kg/sec)
Recirculation Loops (5) 9x10³ kg/sec
Power – 1930 MWt
Reactor Coolant Water Mass – 2x10⁵ kg

Figure 2.1 Coolant flow schematic.



1. INSPECTION AND TESTING OF MAIN STEAM ISOLATION VALVES
2. HIGH LEVEL IN MOISTURE SEPERATOR DRAIN TANK
3. OVERHAUL OF CONTROL ROD MECHANISMS
4. HIGH AMBIENT TUNNEL TEMPERATURE
5. SCHEDULED-INTEGRATED CONTAINMENT LEAK RATE TEST
6. SCHEDULED-TURBINE CONTROL VALVE INSPECTION
7. SCHEDULED-REMOVAL OF POISON CURTAIN AND INSPECTION OF TURBINE & PARTIAL REFUELING
8. FLEXIBLE DISCHARGE LINE FROM AIR COMPRESSOR FAILED
9. INCREASING UNIDENTIFIED LEAK IN DRY WELL
10. REFUELING-PARTIAL TURBINE AND GENERATOR INSPECTION
11. FALSE TRIP OF SENSOR IN REACTOR PROTECTION SYSTEM #1 DURING CALIBRATION TEST OF MAIN STEAM LINE RADIATION SENSORS
12. INCREASE OF REACTOR PRESSURE DUE TO MAIN STEAM ISOLATION VALVE TEST
13. LOSS OF GENERATOR FIELD DUE TO OPERATOR ERROR
14. PARTIAL REFUELING & TURBINE GENERATOR INSPECTION
15. UNIDENTIFIED LEAKAGE IN PRIMARY CONTAINMENT
16. SCHEDULED-TO INSPECT & REPAIR SHOCK AND SWAY ARRESTORS INSIDE PRIMARY CONTAINMENT

Figure 2.2 Oyster Creek electrical production (from Semi-Annual Reports).

changing the coolant recirculation pump speed which alters the reactor recirculation flow.

Electrical power is produced by a 640,000-KW, 1800-rpm, tandem-compound six-flow 2-stage reheat steam turbine-generator. The turbine has one double-flow, high pressure and three double-flow, low pressure elements. Exhaust steam from the high pressure turbine passes through moisture separators and reheaters before entering the three low pressure units. The separators reduce the moisture content of the steam to less than 1 percent by weight.

Steam passes from the low pressure units to three horizontal, single pass, divided-water box, deaerating-type condensers. These are designed to produce a back pressure of 2.5 cm Hg absolute at rated load with 9° C cooling water. Deaeration by a steam jet air ejector is provided in each condenser to remove air from normal inleakage, hydrogen and oxygen gases due to dissociation of water in the reactor, and gaseous radionuclides.

Condensate is pumped from the condenser hotwells through the condensate demineralizers by the three condensate pumps. The full-flow condensate demineralizer system (Figure 2.1) ensures the supply of water of the required purity to the reactor. This demineralizer system removes corrosion products from the turbine, condenser, and shell side of the feedwater heaters, protects the reactor against condenser tube leaks, and removes condensate impurities which might enter the system in the makeup water.

The condensate demineralizer consists of seven mixed-bed units (including one spare) sized for rated load condensate flow. Demineralizer resins are normally regenerated and reused. Any radioactive material removed from exhausted resins by rinse solutions is transferred to the radioactive waste system (see Section 4.1).

From the condensate demineralizer, water is pumped by the feedwater pumps through feedwater heaters and back to the reactor vessel.

2.1.3 *Reactor cleanup and demineralizer system.(3)* The primary purposes of the reactor cleanup demineralizer system are to reduce concentrations of:

1. corrosion products;
2. radioactive materials (primarily radioiodine) produced in the core;
3. transient bursts of Cl^- ions to maintain acceptable levels of Cl^- in the primary water system;
4. coolant radioactivity during refueling.

The cleanup system provides continuous purification of a portion of the recirculation flow with a minimum of heat loss from the cycle. It can be operated during startup, shutdown, and refueling operations, as well as during normal operations.

Water is normally removed at reactor pressure and cooled in a regenerative and a nonregenerative heat exchanger, reduced in pressure, filtered, demineralized, and pumped through the shell side of the regenerative heat exchanger to the reactor.

The cleanup filters are pressure precoat type, using a nonsilicious filter aid. Two full-size filters are provided for continuous operation, with one filter being on standby. The flow rate through the mixed-bed cleanup demineralizer was 25 kg/s (2.0×10^5 lb/hr) at the time of the study.*(4)* Spent cleanup resins are not normally regenerated because of the radioactivity of the impurities removed from the reactor coolant, but are sluiced from the demineralizer vessels directly to the radwaste system for disposal.

2.1.4 *Circulating water system.* Circulating cooling water is transferred from Forked River through the main condenser by 4 pumps at the rate of 1.7×10^6 kg/min (450,000 gpm). It is returned to Oyster Creek carrying with it the heat extracted from the steam. The maximum temperature increase in the circulating cooling water is 12.8° C (23° F).

To limit temperature increase in the Oyster Creek, three 1.0×10^6 kg/min (260,000 gpm) dilution pumps are available to take water from the intake and by-pass the condenser, discharging directly to Oyster Creek. The dilution flow is adjusted as required to meet temperature limits in Barnegat Bay.

2.1.5 *Paths of radionuclides from the reactor coolant system.(2–4)* The radionuclides in the reactor coolant water are fission products and activation products. The fission products in the water are formed within the uranium oxide fuel and enter the water through imperfections in the Zircaloy cladding of the fuel elements. Other possible sources of fission products — apparently minor — are fuel that contaminates the surface of new fuel elements ("tramp uranium") and fuel that passes into reactor coolant water from failed fuel elements. The activation products in reactor coolant water are formed by neutron irradiation of the water and its contents (including gases and dissolved or suspended solids) and of materials in contact with the coolant (container and structural surfaces, fuel and control rod cladding) that subsequently corrode or erode.

The radionuclides in the reactor coolant water circulate and decay within the system and may deposit as "crud" (which may later recirculate). They are retained by the cleanup demineralizer or condensate demineralizer or leave the system with gases and liquids. The cleanup demineralizer resin is periodically replaced and processed for shipment off-site as solid waste. The condensate demineralizer is periodically regenerated, and the regenerant solution is processed in the liquid waste system.

During routine operation, water and associated gases leave the reactor coolant system through leaks and by intentional discharge for volume control. At the time of the study, losses of 6.5 x 10^4 liters/day (17,200 gpd) from the reactor coolant system included 5.7 x 10^4 liters/day (15,000 gpd) water leakage to equipment drains and 8.3 x 10^3 liters/day (2,200 gpd) of water as steam leakage to turbine building, reactor building and radwaste building air.*(4)* Another estimate of reactor coolant water loss was based on the AEC 1200-MWe model BWR.*(5)* Adjusted to Oyster Creek plant size, this estimate is 1.9 x 10^4 liters/day (5,000 gpd) loss to equipment drains and 4.5 x 10^3 liters/day (1,200 gpd) loss to building air for a total loss of 2.34 x 10^4 liters/day (6,200 gpd).

Radionuclides in the leaking water are expected to be equal to or less than the concentrations observed in samples of reactor coolant water. Those leaks which release steam or condensate would be expected to have higher concentrations of volatile radionuclides and lower concentrations of nonvolatile radionuclides. Volatile radionuclides are vented continuously from the reactor, turbine and radwaste buildings, but accumulate in the drywell until it is vented.

2.1.6 *Other liquids on site.(3)* Several ancillary water systems exist at the station, but only the first three of the following are believed to result in radioactive discharge:

1. Radioactive waste treatment system. The system for gases is described in Section 3.1.1, and for liquids, in Section 4.1.1.
2. Fuel storage pool filtering, demineralizing and cooling. This system is designed to filter and demineralize the pool water and remove decay heat from spent fuel which is stored in the fuel pool. The fuel pool filter and demineralizer, which may become radioactive, are located in the radwaste building. Cooling water for the heat exchangers is supplied by the reactor building closed cooling water system.
3. Refueling water. The cavity above the reactor vessel is flooded during refueling. Purity of the water during refueling is maintained by the reactor cleanup demineralizer. Fuel removed from the reactor is transferred underwater to the fuel storage pool. Excess primary system water after the completion of refueling is discharged through the pool filter and demineralizer and reactor cleanup system to the condenser hotwell. It is returned to condensate storage through the condensate pump and demineralizers.
4. Fire protection system. The fire protection system furnishes water to all points throughout the plant area and to buildings where water for fire-fighting may be required. The fire protection water is fresh water stored on site in the 3.8 x 10^7 liter (10,000,000 gal.) storage pond.
5. Makeup water system. Makeup water requirements for the plant are provided by processing well water, or water from Oyster Creek, or a mixture of the two. The system utilizes a coagulator followed by charcoal filters, carbon filters, 2 cation-anion primary demineralizers, and a final mixed-bed polishing unit. A 1.1 x 10^5-liter (30,000 gal.) makeup demineralizer water storage tank is provided to store water for normal requirements. The required quality of water used as makeup is—

pH	7.0
Conductivity	$<$ 1.0 micromho at 25° C
Silica	$<$ 0.01 ppm as SiO_2
Chloride	$<$ 0.01 ppm as Cl

6. Cooling water systems. A closed loop, forced circulation, cooling system (reactor building closed cooling water system) is employed for cooling the reactor plant equipment. Seawater from the service water system cools this system through heat exchangers. The turbine oil coolers, hydrogen coolers, stator coolers, and similar associated equipment are cooled by another closed loop system located in the turbine building (turbine building closed cooling water system). Seawater from either the service water or circulating water systems cools this system through heat exchangers.

   The service water system provides 4.5 x 10^4 liters/min (12,000 gpm) of water for cooling plant components. Service water is taken from the Forked River intake and is discharged into the Oyster Creek discharge canal.
7. Emergency systems. Three systems are provided for emergency shutdown and cooling of the reactor:
   a. Standby liquid control system. The liquid poison backup systems can shut down the reactor should the control rods fail to

    function. This system consists of devices which can inject a sodium pentaborate solution from a 15,000-liter storage tank into the reactor vessel.
    b. Standby core cooling system. The standby core cooling system is designed to remove the decay heat from the core following a postulated loss-of-coolant accident. Duplicate independent systems are available to take water from the 2.4 x 10^6-liter absorption pool and spray it over the core.
    c. Primary containment spray cooling system. A containment system is installed within the primary containment structure which would take water from the absorption pool and from service water to remove decay heat from the primary containment system in the event of an accident.
8. Sewage treatment system. Water for domestic and sanitary purposes is taken from a deep well on the site. Domestic and sanitary wastes from the unrestricted, nonradioactive areas of the plant are treated in a packaged sewage treatment facility. The aerobic system utilizes the activated sludge process, and treats about 4000 liters/day of raw wastewater. Effluent from this system is chlorinated and released to the discharge canal.

2.1.7 *Samples.* To identify potential radioactive effluents at the Oyster Creek nuclear power station, samples of reactor water where radionuclides occur at much higher concentrations and are therefore more easily detected than at the point of release were obtained from the recirculation loops (see Figure 2.1). The following reactor water samples were provided in plastic bottles by station personnel:

1. 1 liter, acidified, collected Aug. 31, 1971 at 1522;
2. 500 ml, collected Aug. 31, 1971 at 1522;
3. 100 ml, acidified, collected Nov. 30, 1971 at 1100;
4. 20 ml, collected Nov. 30, 1971 at 1100;
5. 1 liter, acidified, collected Mar. 14, 1972 at 1000;
6. 500 ml, collected Mar. 14, 1972 at 1000;
7. 150 ml, collected Dec. 13, 1972 at 0825.

The unacidified samples were analyzed for ^{3}H, ^{14}C, ^{35}S, and radioiodine; the acidified samples, which contained 10% by volume of conc. nitric acid to reduce deposition of radionuclides on the walls of the bottle, and sample no. 7 were analyzed for other radionuclides.

2.2 Analysis

2.2.1 *General.* Aliquots of all samples were counted for gross alpha and beta radioactivity, examined with gamma-ray spectrometers and analyzed radiochemically. Analyses were performed for high-yield fission products and common activation products. Because radioactive decay between sampling and analysis was usually more than 24 hours, radionuclides with half-lives less than 6 hours could not be measured. Aliquot volumes for individual analyses ranged from 1 to 200 ml.

A special effort was made to measure radionuclides that emit only weak beta particles, such as 12.3-yr ^{3}H (maximum beta particle energy, 18 keV), 5,730-yr ^{14}C (158 keV), 88-d ^{35}S (167 keV), and 92-yr ^{63}Ni (67 keV). Radionuclide concentrations were computed from count rates obtained with detectors calibrated with radioactivity standards as functions of gamma-ray or average beta-particle energies. All values were corrected for radioactive decay or ingrowth, and are given as concentrations at sampling time. Half-lives and branching ratios are from recent publications.*(6–9)*

The difficulty of retaining radionuclides in solution was reported in earlier publications,*(10–12)* and was also observed during this study by measuring radionuclides that remained on the empty plastic sample containers when the liquid samples were poured out after contact periods of days to weeks. Even with acidification, losses of 10–50% were observed for radionuclides such as ^{51}Cr, ^{54}Mn, ^{58}Co, ^{60}Co, and ^{59}Fe. The following techniques were applied to prevent underestimating the radionuclide content of liquid samples:

1. Cutting the empty sample bottles into small pieces and measuring gamma-ray emitters by counting them in a container for which the counting efficiency had been determined.
2. Collecting the liquid sample on a dried sponge in a container to saturate the sponge with the liquid at a volume calibrated for the counting efficiency of gamma-ray emitters.
3. Passing solutions of low ionic content immediately through cation- and anion-exchange membrane filters* to collect

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*Acropor SA-6404 and Acropor SB-6407, distributed by the Gelman Instrument Co., were found to be satisfactory for this ionic separation.

particulate and ionic radionuclides on the filters for analysis by a gamma-ray spectrometer. The filtrate was also analyzed.

2.2.2 *Gamma-ray spectrometry.* Radionuclides emitting gamma rays were identified by their characteristic gamma-ray energies in aliquots of reactor coolant water by multichannel spectrometry with a Ge(Li) detector. Spectral analyses were obtained at appropriate intervals to eliminate interference by shorter-lived radionuclides, to measure half-lives and confirm the identity of the radionuclides.

The large number of nuclides and the large differences in concentration in the reactor water samples made identification after collection on ion-exchange papers convenient. This technique also differentiated between particulate, ionic and neutral species of the radionuclides. Sample no. 7 (Section 2.1.7) was analyzed by filtering a 35-ml aliquot of the reactor water through a suction apparatus which consisted of 3 cation- and 2 anion-exchange papers in series. The papers were separated and transferred individually to containers for spectral analysis. The 35-ml filtrate was collected and also analyzed. Figures 2.3, 2.4, and 2.5 show the Ge(Li) spectra of each fraction 5 days after collection.

The radionuclides ^{58}Co, ^{60}Co, ^{134}Cs, ^{136}Cs, ^{137}Cs, and ^{239}Np were predominant on the cation papers and ^{51}Cr, ^{99}Mo, ^{131}I, ^{133}I, ^{135}I, ^{133}Xe and ^{140}La on the anion paper. The ^{133}Xe was produced by beta decay of the ^{133}I. Only about 1 percent or less of the radionuclides passed through both filters and were in the filtrate.

Sample (6) and another aliquot of sample (7) (Section 2.1.7) were analyzed by adding 20-ml to a dry sponge in a falcon container. This volume just saturated the sponge and expanded it to the 35 ml geometry selected for calibration. This technique enabled the liquid to be transported without losses from spillage or from deposition on container walls. Calculation of individual radionuclide concentrations from Ge(Li) spectra of these samples agreed with results obtained utilizing the ion-exchange technique above.

Reactor water samples were analyzed by obtaining repeated spectra over a period of several weeks after collection. Initially, gamma rays of energies below 160 keV from relatively short-lived radionuclides were obscured by the high ^{133}Xe content, which also produced an excessive counter dead time. This interference was totally eliminated by boiling and stirring a 35-ml aliquot with 5 ml conc. HCl. Replicate tests indicated that less than 1% of the ^{131}I volatilized in this process.

Samples were analyzed by either an 11.4– or 54-cm^3 Ge(Li) detector or a 10-cm x 10-cm NaI(Tl) detector with multichannel spectrometers. For those samples containing fewer radionuclides at lower levels of radioactivity, the higher energy resolution of the Ge(Li) detector was generally unnecessary, and the higher counting efficiency of NaI(Tl) detectors was advantageous.

2.2.3 *Radiochemistry.* Radiochemical separations were performed to confirm spectral identification by gamma-ray energy and half-life, measure radionuclides more precisely and at lower concentrations than by instrumental analysis of a mixture, and detect radionuclides that emit only obscure gamma rays or none at all.*(13)* After chemical separation, the following detectors were used: NaI(Tl) crystal plus multichannel analyzer for photon-emitting radionuclides; low-background end-window Geiger-Mueller (GM) counter for ^{14}C, ^{32}P, ^{35}S, ^{89}Sr, ^{90}Sr, and ^{185}W; liquid scintillation spectrometer for ^{3}H, ^{14}C and ^{63}Ni; and xenon-filled proportional counter plus spectrometer for ^{55}Fe. Measurements with the GM detector included observation of the effect of aluminum absorbers on count rates to determine maximum beta-particle energies and thus confirm radionuclide identification.

2.3 Results and Discussion

2.3.1 *Radioactivity in reactor water.* Iodine-133, ^{135}I, ^{99m}Tc, and ^{239}Np were the most abundant of the measured radionuclides listed in Table 2.1. The sum of all measured radionuclides, except ^{3}H and the noble gases, for each sampling period ranged between 0.07 and 0.16 uCi/ml. In comparison, the sum of all measured radionuclides reported by Pelletier except ^{3}H and the noble gases was 0.29 uCi/ml.*(4)* However, radionuclides with half-lives less than 6 hours contributed 0.22 uCi/ml to the latter value. Major short-lived contributors were 2.71-hr ^{92}Sr, 2.28-hr ^{132}I, 52.3-min ^{134}I, 32.2-min ^{138}Cs, 83.2-min ^{139}Ba and 18.3-min ^{141}Ba.

Several high-yield fission products could not be detected at the limiting sensitivity of approximately 1 x 10^{-4} uCi/ml (see footnote 3 to Table 2.1). Most of the other radionuclides are neutron activation products that have been reported earlier.*(10–12)* They are formed in water, steel, boron (in the boron control curtains), antimony (in the Sb-Be neutron sources), and zirconium (in the Zircaloy-2 cladding). The activation products ^{14}C and ^{124}Sb were found at relatively low concentration, as in previous studies.*(11,12)* The gross alpha radioactivity was low in all samples, 5 x 10^{-7}

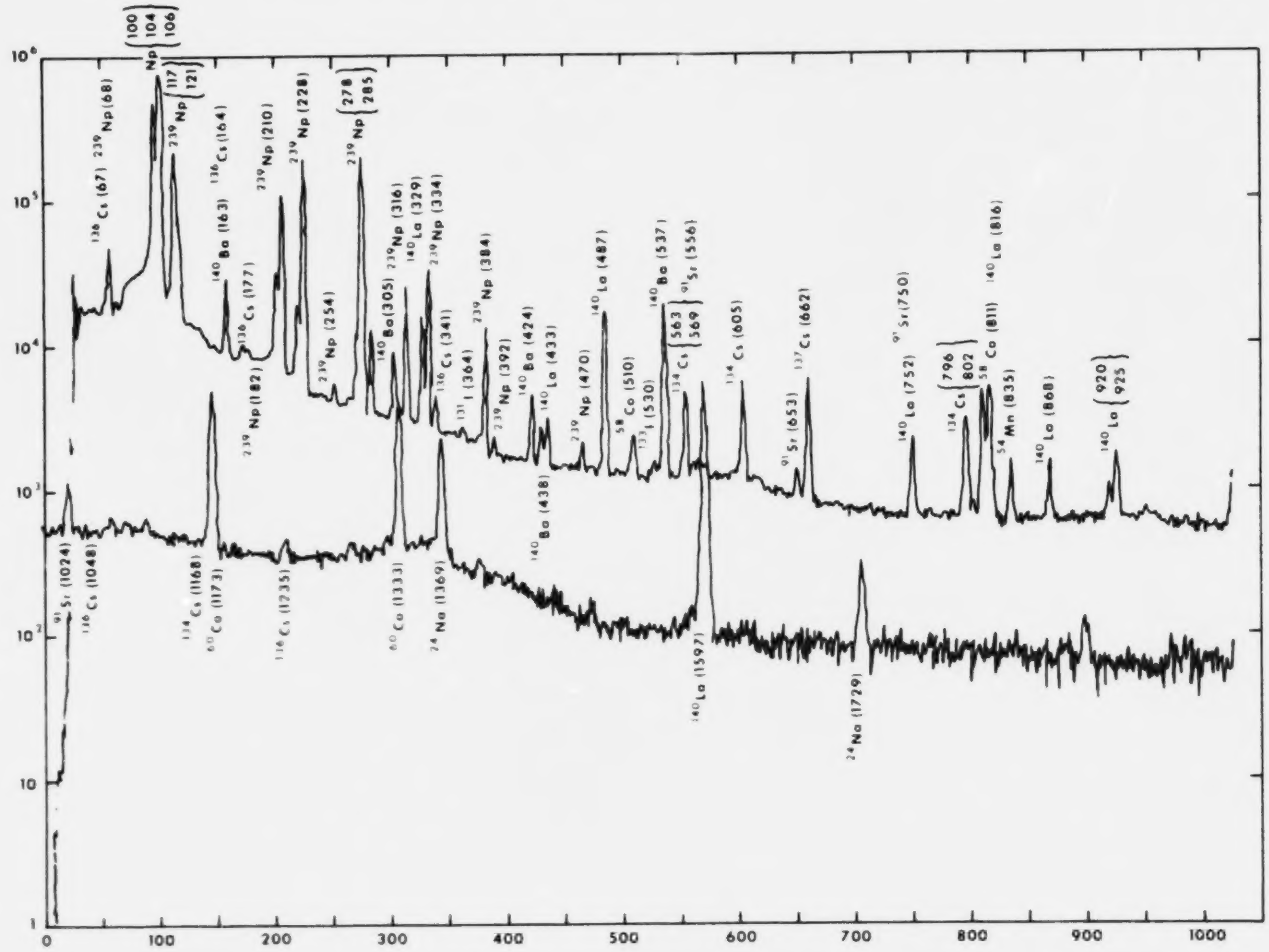

Figure 2.3 Gamma-ray spectrum of radionuclides from reactor water retained on cation exchange paper, 0-2000 keV.
Detector: Ge(Li), 11.4 cm^3.
Sample: Cation exchange paper containing activities from 20 ml, collected Dec. 13, 1972 at 0825
Count: Dec. 15, 1972, 97.6 minutes.

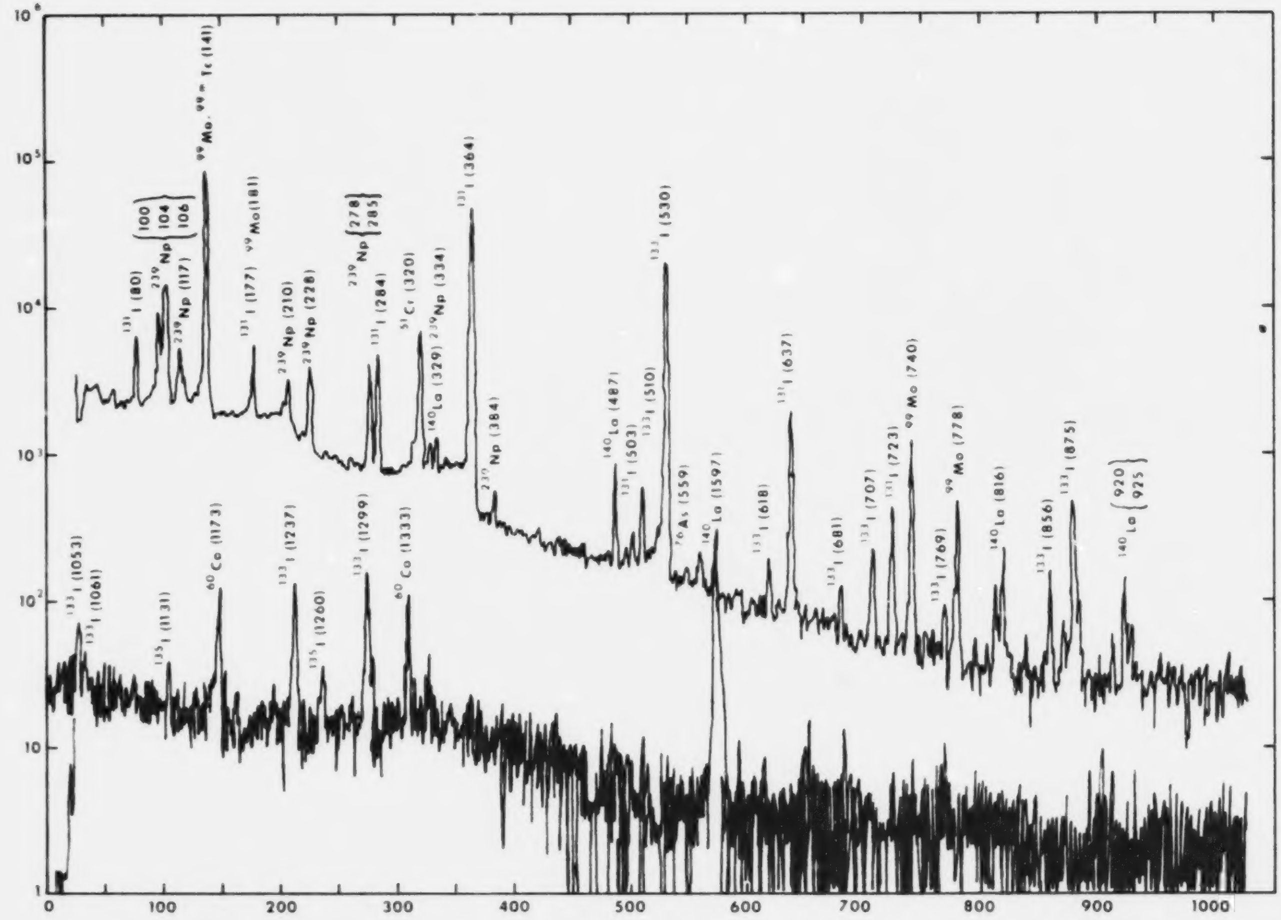

Figure 2.4 Gamma-ray spectrum of radionuclides from reactor water retained on anion exchange paper, 0-2000 keV.
Detector: Ge(Li), 11.4 cm^3.
Sample: Anion exchange paper containing activities from 20 ml, collected Dec. 13, 1972 at 0825.
Count: Dec. 16, 1972, 19.8 minutes.

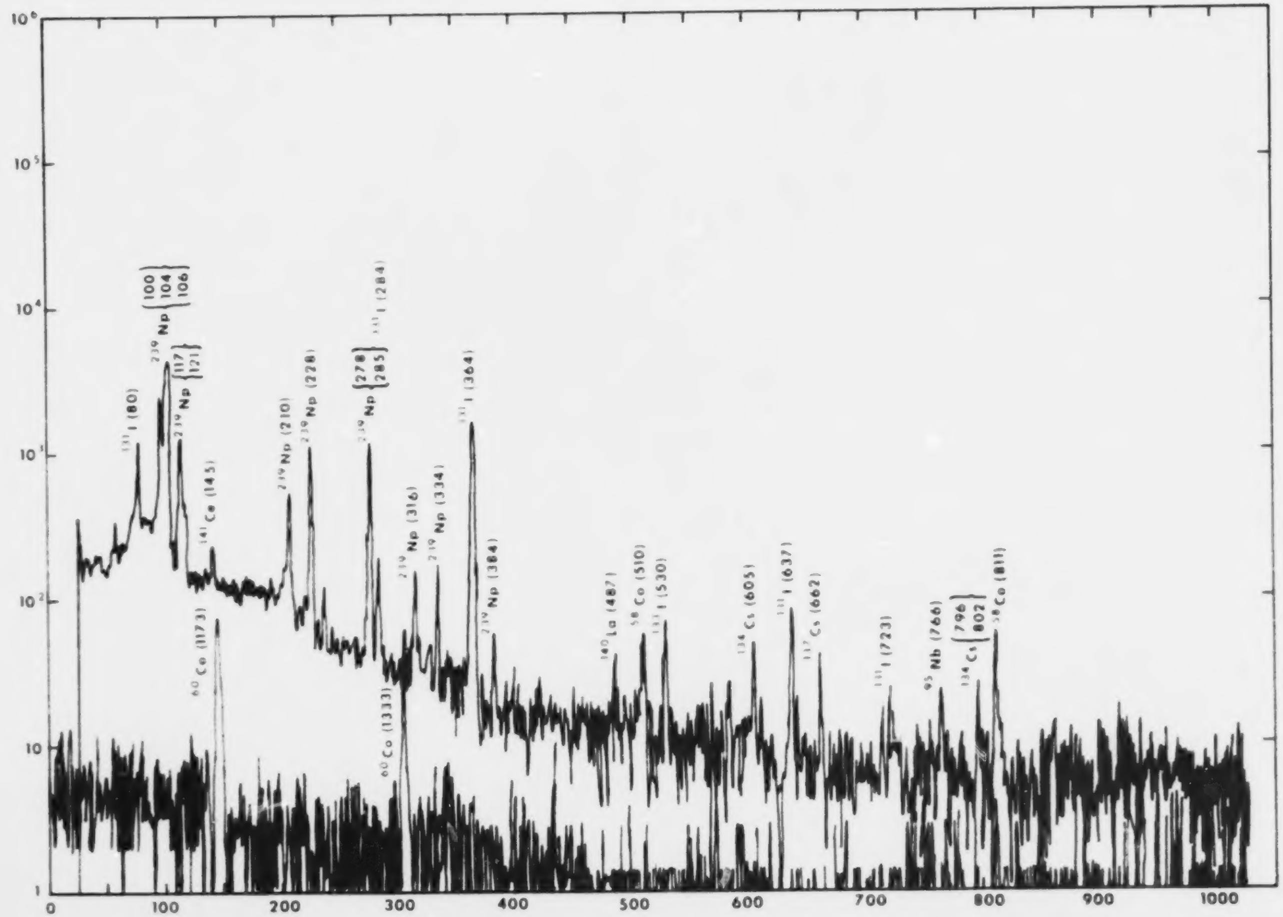

Figure 2.5 Gamma-ray spectrum of radionuclides from reactor water not retained on cation or anion papers, 0-2000 keV.
Detector: Ge(Li), 11.4 cm^3.
Sample: Effluent from cation-anion exchange paper containing activities from 20 ml, collected Dec. 13, 1972 at 0825.
Count: Dec. 19, 1972, 99.8 minutes.

Table 2.1 Radionuclide Concentration in Reactor Water, µCi/ml

Radionuclide		1971		1972	
		August 31	November 30	March 14	December 1
			Fission Products		
50.5 -d	^{89}Sr	1.5×10^{-5}	3.5×10^{-5}	7.0×10^{-5}	4.1×10^{-4}
28.5 -yr	^{90}Sr	7×10^{-6}	3.8×10^{-6}	3.0×10^{-6}	3.5×10^{-5}
9.7 -hr	^{91}Sr	$\sim 5.8 \times 10^{-3}$	$\sim 7.3 \times 10^{-3}$	4.8×10^{-3}	8.3×10^{-3}
65 -d	^{95}Zr**	4.1×10^{-5}	8.2×10^{-5}	2.4×10^{-6}	1.1×10^{-5}
35.1 -d	^{95}Nb**	$< 3 \times 10^{-6}$	1.1×10^{-4}	1.3×10^{-6}	2.1×10^{-5}
66.2 -hr	^{99}Mo**	1.4×10^{-3}	8.4×10^{-4}	9.2×10^{-4}	2.5×10^{-3}
6.0 -hr	^{99m}Tc	2.1×10^{-2}	1.8×10^{-2}	3.8×10^{-2}	ND
39.6 -d	^{103}Ru	8×10^{-6}	7.8×10^{-5}	1.2×10^{-6}	$< 5 \times 10^{-6}$
36 -hr	^{105}Rh	NA	$\sim 4.0 \times 10^{-4}$	2.7×10^{-4}	1.4×10^{-4}
8.06-d	^{131}I	6.9×10^{-3}	1.1×10^{-3}	7.6×10^{-3}	3.5×10^{-3}
20.9 -hr	^{133}I	2.2×10^{-2}	1.5×10^{-2}	2.6×10^{-2}	ND
6.7 -hr	^{135}I	$\sim 2.5 \times 10^{-2}$	$\sim 2.7 \times 10^{-2}$	2.3×10^{-2}	ND
5.29-d	^{133}Xe	8.6×10^{-4}	6.4×10^{-4}	NA	ND
9.1 -hr	^{135}Xe	1.3×10^{-2}	1.8×10^{-2}	NA	ND
2.07-yr	^{134}Cs***	2.6×10^{-5}	1.7×10^{-5}	4.1×10^{-5}	9.5×10^{-5}
13 -d	^{136}Cs***	3.2×10^{-5}	$< 1 \times 10^{-5}$	3.0×10^{-5}	4.5×10^{-5}
30 -yr	^{137}Cs	6.0×10^{-5}	[illegible]$.0 \times 10^{-5}$	7.1×10^{-5}	1.2×10^{-4}
12.8 -d	^{140}Ba	6.7×10^{-4}	4.7×10^{-4}	6.1×10^{-4}	1.1×10^{-3}
32.4 -d	^{141}Ce	4.4×10^{-5}	9.8×10^{-5}	1.7×10^{-5}	3.7×10^{-5}
33 -hr	^{143}Ce	NA	2.0×10^{-4}	NA	ND
284 -d	^{144}Ce	$< 3 \times 10^{-6}$	1.1×10^{-4}	$< 3 \times 10^{-6}$	$< 3 \times 10^{-6}$
2.34-d	^{239}Np***	1.4×10^{-2}	1.5×10^{-2}	3.6×10^{-3}	4.0×10^{-2}
gross alpha		$< 5 \times 10^{-7}$	$< 2 \times 10^{-7}$	$< 2 \times 10^{-7}$	$< 2 \times 10^{-7}$
	from activation of water, cladding, and construction materials				
12.3 -yr	^{3}H**	1.8×10^{-3}	9.2×10^{-4}	4.5×10^{-3}	4.3×10^{-3}
5730 -yr	^{14}C	$< 1 \times 10^{-6}$	1.5×10^{-5}	$< 1 \times 10^{-6}$	$< 1 \times 10^{-6}$
15.0 -hr	^{24}Na	1.4×10^{-3}	1.9×10^{-3}	1.1×10^{-3}	ND
14.3 -d	^{32}P	3.8×10^{-5}	3.4×10^{-5}	1.5×10^{-5}	1.1×10^{-4}
27.7 -d	^{51}Cr	7.1×10^{-3}	8.6×10^{-4}	4.1×10^{-3}	3.0×10^{-3}
313 -d	^{54}Mn	1.1×10^{-4}	3.8×10^{-3}	2.2×10^{-5}	3.1×10^{-5}
2.7 -yr	^{55}Fe	1.6×10^{-5}	1.5×10^{-2}	1.3×10^{-5}	3.0×10^{-5}
44.6 -d	^{59}Fe	1.0×10^{-4}	2.3×10^{-3}	5.3×10^{-6}	5×10^{-6}
270 -d	^{57}Co	$< 1 \times 10^{-6}$	$< 1 \times 10^{-5}$	$< 1 \times 10^{-6}$	$< 1 \times 10^{-6}$
71.3 -d	^{58}Co	5.3×10^{-4}	1.4×10^{-3}	9.3×10^{-5}	1.7×10^{-4}
5.26-yr	^{60}Co	3.9×10^{-4}	6.4×10^{-3}	2.0×10^{-4}	3.7×10^{-4}
12.8 -hr	^{64}Cu	NA	2.5×10^{-2}	1.3×10^{-3}	3.3×10^{-4}
244 -d	^{65}Zn	NA	NA	1.3×10^{-5}	1.3×10^{-5}
26 -hr	^{76}As	NA	2.9×10^{-3}	5.0×10^{-5}	2.5×10^{-4}
2.7 -d	^{122}Sb	NA	2.3×10^{-3}	2.2×10^{-6}	1.1×10^{-4}
60.2 -d	^{124}Sb***	1.7×10^{-5}	3.9×10^{-4}	$< 1 \times 10^{-6}$	3.7×10^{-6}
5.1 -d	^{183}Ta	NA	NA	NA	3.9×10^{-5}
24 -hr	^{187}W	NA	6.1×10^{-3}	3.3×10^{-5}	5.9×10^{-3}

* Concentration at time of sampling; water at ambient temperature and pressure.

** ^{3}H also results from ternary fission in fuel; ^{95}Zr, ^{95}Nb and ^{99}Mo may also be activation products.

*** Formed by (n,γ) reactions with uranium or fission products.

Notes:

1. NA - not analyzed; ND - not detected because interval between sampling and counting was long compared to the half-life.
2. <values are 3σ counting errors.
3. The following fission products were not detected (usually $< 1 \times 10^{-6}$ µCi/ml): ^{35}S, ^{63}Ni, ^{93}Y, ^{97}Zr, ^{106}Ru, ^{127}Sb, ^{132}Te, and ^{147}Nd. The radionuclides ^{110m}Ag and ^{185}W were also not observed at this minimum detectable level.

Table 2.2 Comparison of Radionuclide Concentrations Measured and Calculated in Reactor Water, µCi/ml

Radionuclide	Average of measured concentrations*	Reported concentrations by AEC**(4)	Calculated from NRC Reg. Guide 1.CC†
		Fission Products	
^{89}Sr	1.3×10^{-4}	1.4×10^{-4}	4×10^{-5}
^{90}Sr	1.2×10^{-5}	5.6×10^{-6}	3×10^{-6}
^{91}Sr	6.5×10^{-3}	3.5×10^{-3}	2×10^{-3}
^{95}Nb	3.3×10^{-5}	NR	3×10^{-6}
^{95}Zr	3.4×10^{-5}	$<2 \times 10^{-6}$	3×10^{-6}
^{97}Zr	$<1 \times 10^{-6}$	NR	2×10^{-6}
^{99}Mo	1.4×10^{-3}	2.1×10^{-3}	8×10^{-4}
^{99m}Tc	2.6×10^{-2}	2.0×10^{-2}	9×10^{-3}
^{103}Ru	2.2×10^{-5}	NR	8×10^{-6}
^{106}Ru	$<1 \times 10^{-6}$	NR	1×10^{-6}
^{131}I	4.8×10^{-3}	3.9×10^{-3}	4×10^{-3}
^{133}I	2.1×10^{-2}	1.7×10^{-2}	2×10^{-2}
^{135}I	2.5×10^{-2}	2.3×10^{-2}	2×10^{-2}
^{132}Te	$<1 \times 10^{-6}$	$<1.1 \times 10^{-5}$	3×10^{-6}
^{134}Cs	4.5×10^{-5}	3.3×10^{-5}	2×10^{-5}
^{136}Cs	2.8×10^{-5}	$<1 \times 10^{-5}$	8×10^{-6}
^{137}Cs	7.0×10^{-5}	5.7×10^{-5}	3×10^{-5}
^{140}Ba	7.1×10^{-4}	5.9×10^{-4}	2×10^{-4}
^{141}Ce	4.9×10^{-5}	6.0×10^{-5}	2×10^{-5}
^{144}Ce	3.0×10^{-5}	NR	2×10^{-6}
^{147}Nd	$<1 \times 10^{-6}$	NR	1×10^{-6}
		Corrosion and Activation Products	
^{3}H	2.9×10^{-3}	2.5×10^{-3}	3×10^{-3}
^{14}C	-4×10^{-6}††	$<1 \times 10^{-6}$	NR
^{24}Na	1.5×10^{-3}	1.4×10^{-3}	3×10^{-3}
^{32}P	4.9×10^{-5}	2.9×10^{-4}	8×10^{-5}
^{51}Cr	3.8×10^{-3}	1.9×10^{-3}	2×10^{-3}
^{54}Mn	9.9×10^{-4}	4.3×10^{-5}	3×10^{-5}
^{55}Fe	3.8×10^{-3}	2.2×10^{-3}	4×10^{-4}
^{59}Fe	6.0×10^{-4}	2.4×10^{-5}	2×10^{-5}
^{58}Co	5.5×10^{-4}	3.3×10^{-5}	8×10^{-5}
^{60}Co	1.8×10^{-3}	7.8×10^{-5}	2×10^{-4}
^{63}Ni	$<1 \times 10^{-6}$	$<5 \times 10^{-7}$	4×10^{-7}
^{65}Zn	$<1.3 \times 10^{-5}$	$<1 \times 10^{-5}$	8×10^{-5}
^{187}W	4.0×10^{-3}	NR	2×10^{-4}
^{239}Np	1.8×10^{-2}	1.8×10^{-3}	3×10^{-3}
gross alpha	2×10^{-7}	$<1 \times 10^{-7}$	NR

* Average of concentrations given in Table 2.1; < values were averaged as 1/2 < value. Only radionuclides for which comparable values were available are included.

** Average of 7 samples collected in January 1972; deviations from the mean were < 20%.(4)

† Concentrations given in Table C-2 of Appendix B, NRC Regulatory Guide 1.CC, adjusted to the parameters of the Oyster Creek reactor.(14)

†† Based on only one analysis.

Note:

1. NR - not reported.

μCi/ml or less. The beta-decay and absorption studies performed on chemically purified phosphorus fractions of each reactor water sample indicated that more than 90 percent of the beta radioactivity was due to ^{32}P. This observation shows that ^{33}P, if present, can be no more than 10 percent of the ^{32}P concentration.

The concentrations of radionuclides measured in reactor water and presented in Table 2.1 were averaged and are compared in Table 2.2 with measurements made by the AEC during a 7-day period in January 1972,*(4)* and with concentrations based on the NRC model for a 3400-MWt boiling water reactor.*(14)* In order for the latter to be applicable to Oyster Creek, the concentrations given by the model were adjusted as described in the NRC Regulatory Guide 1.CC with respect to the Oyster Creek reactor parameters:*(14)* 1930 MWt power, 1.9 x 10^5 kg (4.2 x 10^5 lbs) of water in the reactor vessel, a cleanup demineralizer flow rate of 9.0 x 10^4 kg/hr (2.0 x 10^5 lbs/hr), a steam flow rate of 3.2 x 10^6 kg/hr (7.1 x 10^6 lbs/hr) and a ratio of condensate demineralizer flow rate to steam flow rate of unity (see Section 2.1). The adjustment factors, which are multiplied by the NRC reference reactor concentrations to approximate the Oyster Creek reactor water concentrations, were about 0.67 for the radioiodines and 0.39 for all other radionuclides. The adjustment of the NRC reference reactor water ^3H concentration is based on an appearance rate in the water of 120 Ci/yr and the weight of reactor vessel water in the Oyster Creek reactor, 1.9 x 10^5 kg, with a leakage rate of 6.5 x 10^4 kg/d.

For many of the radionuclides the three sets of values are in agreement. The concentration predicted by the NRC model agree with those measured within a factor of 5 for more than 70 percent of the radionuclides. Of the fission products, the measured concentrations of ^{95}Nb, ^{95}Zr and ^{144}Ce are significantly higher than the predicted values — in general, most measured concentrations are high compared to the predicted concentrations. This is particularly true of the corrosion and activation products, which can be partially explained by the high concentrations measured in the November 30, 1971, sample (see Table 2.1). This sample was collected shortly after startup, a period during which high levels of corrosion products might be expected in the reactor water. See, for example, the high concentrations of ^{54}Mn, ^{55}Fe, ^{59}Fe, ^{58}Co, ^{60}Co, etc. for this period. Omission of the November 30 data produces much better agreement with most of the predicted activation product concentrations.

Variations between measurements at different times may be expected, as these nuclides are associated mainly with "crud" and are either in or out of solution depending on their chemical behavior in reactor water. They may be deposited in the system resulting in low measured concentrations at one time or be resuspended or redissolved at another time. Pelletier has reported that concentrations of radionuclides in the Oyster Creek reactor water not only vary with time, but also differ by factors of 5 to 7, depending upon the location in the system at which the sample is collected.*(4)* Fission and activation product concentrations in reactor water are also affected by other variables, including the quality of the fuel elements, the occurrence of shutdowns, the length of operation, and the rate of reactor water purification and turnover.

The activity ratios of $^{58}Co/^{60}Co$ and $^{54}Mn/^{60}Co$ measured in the reactor water by this laboratory are 0.31 and 0.55, respectively. These ratios are similar to those reported by the AEC,*(4)* and are consistent with measurements of the liquid radwaste (see Table 4.1, and Appendix B.2). The NRC model correctly predicts the $^{58}Co/^{60}Co$ activity ratio but not the $^{54}Mn/^{60}Co$ ratio.

2.3.2 *Tritium in reactor water.* The average measured ^3H concentration shown in Table 2.2 is in close agreement with the concentration reported by Pelletier,*(4)* and with that predicted by the NRC model.*(14)* During this period, the station operator did not report ^3H concentrations in reactor water at the Oyster Creek station.

The probable major sources of tritium in the reactor water are: (1) ternary fission in the fuel, (2) activation of deuterium in the water, and (3) neutron-boron reactions in the boron control curtain. It is difficult to ascertain which of these sources is the most important. Even though the production of ^3H is 2000 times greater by fission and 700 times greater from boron relative to that from deuterium, the diffusion rate through the Zircaloy-2 cladding and from the boron is unknown.*(15)* Experience has indicated, however, that the latter is quite small. Estimated formation rates of tritium from the three sources for a 1930-MWt GE-BWR with a 0.8 capacity factor follow:

Source	Location	Formation rate,*(14)* μCi/s	Appearance rate in reactor water, μCi/s	Annual production Ci
deuterium	reactor water	0.20	0.20	6.4
fission	in fuel	380	0.46*	14.5
boron	in control elements	155	0.16**	5.0
				25.9

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* based on an appearance rate of 3 x 10^{-4} μCi/s-MWt *(15)*

**Assumes a transfer to reactor water equal to that from the fuel cladding, 0.10 percent.

Approximate appearance rates in the reactor water are listed in the fourth column. The appearance rate from the deuterium in the water is equal to the formation rate. The appearance rate from fission is taken from the literature,*(15)* while the transfer to the water from the boron curtains is assumed to be of the order of that through fuel cladding, 0.1 percent. The estimated annual production of tritium from each source appearing in reactor water is given in the last column with their sum, about 26 Ci. This estimated annual production of ^{3}H is low, considering that the annual discharge was about 40 Ci in liquids (see Appendix B.3) and 27 Ci in gas, mostly as water vapor (see Section 3.3.6). A better estimate of the tritium production can be made using the NRC Regulatory Guide 1.CC which predicts a steady-state condition to exist relative to ^{3}H in the reactor water and a release of 0.025 Ci/yr-MWt through liquid and vapor pathways. Adjusted to the Oyster Creek BWR, a ^{3}H production of approximately 50 Ci/yr is predicted, a value more closely approximating the measurements. As the boron control curtains were removed in October 1971 with no apparent decrease in the quantity of ^{3}H discharged, the appearance rate of ^{3}H in reactor water from the boron curtains may be overestimated in the above tabulation; that due to fission may be underestimated by a factor of about 4. Because the production of ^{3}H from fission is very large compared to that by activation of deuterium, any significant transfer through the cladding should be readily detectable in the reactor water.

The ^{3}H concentrations measured in Oyster Creek reactor coolant during this study compare as follows to those reported from other BWR power stations:*(15)*

Station	Period	Reactor water, nCi/ml
Oyster Creek	1971–1972	0.9–4.5
Nine Mile Point	1970	0.9
Dresden-1	1968	1.3–1.7
Dresden-2	1970	0.2–1.0
Millstone Point	1971	0.6–0.9
Monticello	1971	0.6–1.1

The ^{3}H concentrations at other BWR stations are similar to those measured at Oyster Creek, and are about three orders of magnitude lower than were observed at the pressurized water reactors utilizing stainless-steel-clad fuel.*(11,12)*

2.4 References

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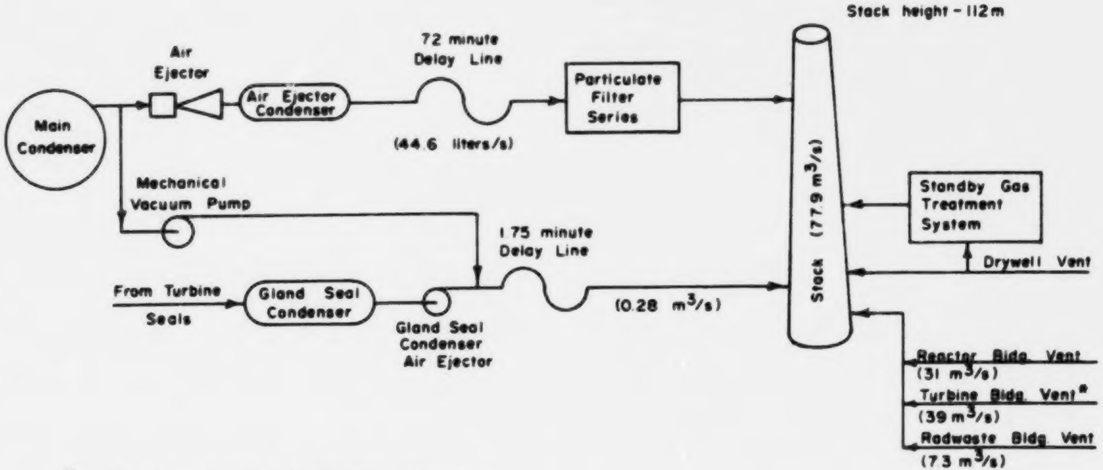
3. AIRBORNE RADIOACTIVE DISCHARGES

3.1 Gaseous Waste System and Samples

3.1.1 *Gaseous waste system.* The gaseous waste treatment system at Oyster Creek during this study was typical of then current techniques at boiling light-water reactors. Non-condensable gases are removed continuously from the reactor steam system, diluted with large volumes of air after a short delay, and discharged through a tall stack. The effluent airborne radionuclides are either gases — fission-produced tritium, krypton, xenon and iodine and activation-produced tritium, carbon, oxygen and nitrogen — or particles. The movement of airborne radioactivity from the reactor to discharge is depicted in Figure 3.1.*(1–8)* A program to improve the waste system to reduce the amounts of effluent radioactivity is being considered by the station operator.*(3)*

Most radioactivity discharged to the stack is gas separated directly from steam in the three main condensers. This gas contains hydrogen and oxygen from radiolytic decomposition of reactor coolant water, air that has leaked into the system, water vapor and trace quantities of fission and activation products. After passing through the turbines, the gas is separated from condensed steam by steam jet air ejectors (SJAE) on the condensers and passed to a 193-m^3 pipe. The approximately one-hour passage through the delay pipe permits removal of most radionuclides by physical decay, especially the abundant activation products of air — 10-min ^{13}N, 7.1-s ^{16}N and 29-s ^{19}O. Other radionuclides with half-lives of 10 min or less are reduced to at least one percent of their initial activity. The discharged radioactivity consists mostly of ^{83m}Kr, ^{85m}Kr, ^{87}Kr, ^{88}Kr, ^{133}Xe, ^{135m}Xe, ^{135}Xe, and ^{138}Xe.

Gas passing through the delay line is held up, according to station staff, 50 to 70 minutes, depending on the flow rate.*(2)* Delay times measured in early 1972 were found to be 72 and 75 min when the estimated flow rate was 44.6 cc/s (94.4 cfm) (some discrepancy exists since the station reported a 25 percent higher flow rate at the time*(7)*). At the end of the delay line, the gas passes through two high-efficiency particulate air (HEPA) filters (nominal particle removal efficiency of 99.95 percent for 0.3-µm size)to remove accompanying aerosols, particularly the radioactive progeny of decayed gases.


Stack height - 112 m
Air Ejector
72 minute Delay Line
Main Condenser
Air Ejector Condenser
Particulate Filter Series
(44.6 liters/s)
Stack (77.9 m³/s)
Mechanical Vacuum Pump
Standby Gas Treatment System
1.75 minute Delay Line
Drywell Vent
From Turbine Seals
Gland Seal Condenser
(0.28 m³/s)
Gland Seal Condenser Air Ejector
Reactor Bldg. Vent (31 m³/s)
Turbine Bldg. Vent* (39 m³/s)
Radwaste Bldg. Vent (7.3 m³/s)

*17 m^3/s from Turbine Building roof exhausters to atmosphere during warm weather (at 33 m)

Figure 3.1 Gaseous Waste Disposal System.

Air inleakage to the turbine is prevented by passing 0.1 percent of the steam through the shaft gland seal annulus. The steam is then condensed and returned to the reactor coolant system. Noncondensable gases are removed by a SJAE at the condenser and vented to the stack through a 1.75-min holdup pipe at a release rate of 0.28 m^3/s (600 cfm).*(7)*

Gaseous wastes are diluted at the stack by ventilation air exhausted from site structures. The air flows at 31 m^3/s (65,000 cfm) from the reactor building, 7.3 m^3/s (15,000 cfm) from the radwaste building, and 39 m^3/s (82,400 cfm) from the turbine building.*(3)* During warm weather, air in the upper level of the turbine building is discharged directly to the atmosphere at 17 m^3/s (36,000 cfm) through roof exhausters at an elevation of 33 m (108 feet).

Building ventilation air becomes contaminated from many small sources of steam leaks and from liquid leakage through valve stems, pump seals or flanged connections. Airborne radioactivity is released as it separates from steam or as a portion of the liquid evaporates before drainage. The Oyster Creek staff has indicated that small amounts of noble gases originate in the fuel pools and cleanup demineralizer area in the reactor building and in the steam leaks in the heater bay and condensate area of the turbine building.*(3)* The Environmental Statement assumed steam leakage rates during reactor operation to be 230 kg/hr in the reactor building, 770 kg/hr in the turbine building, and negligible in the radwaste building.*(6)* These are also the rates estimated for a model BWR plant by the AEC*(9)*and the EPA.*(10)*

Minor sources of airborne radioactivity released to the stack without treatment include:

1. Air in the normally-isolated drywell (the reactor primary containment) and the suppression chamber may become radioactive from inleakage of radioactive gases or by activation with neutrons. The drywell and chamber are purged directly to the stack without treatment before they are opened for refueling or maintenance. The free air volume has been specified to be 8.64×10^3 m^3 (305,000 ft^3)*(4)* or 5.10×10^3 m^3 (180,000 ft^3);*(1)* the former value may include the volume of the suppression chamber located adjacent to the drywell.

2. Mechanical vacuum pumps remove noncondensable gases from the main condensers during reactor startup when steam to operate the SJAE is unavailable. The off-gases are vented to the holdup pipe used for turbine gland seal leakage. The pumps are nominally operated for 4 hrs during startup.*(9)*

The stack stands 112 m (368 ft) above ground level and 119 m above mean sea level. Its diameter at the top is 2.5 m (8.25 ft) and, for an effluent linear velocity of 15.9 m/s, the discharge rate is 77.9 m^3/s. A probe located at 81 m (265 ft) is used to withdraw samples of stack effluent continuously at a nominal rate of 1 liter/s (2 cfm). The air sample is piped to the base of the stack and passed sequentially through a 5-cm-dia. glass fiber filter for retention of particles, a 27-g bed of activated charcoal (Cesco type B cartridge) for sampling radioiodines, and a radiation detector for monitoring radioactive noble gas effluent. At the time of the study, the filter and cartridge were normally changed every three days and analyzed for radionuclide contents.

At the time of the study, off-gas from the SJAE was sampled daily. A gross radioactivity analysis was performed with a NaI(Tl) detector after a 2-hour waiting period. Samples taken on Wednesdays were analyzed for specific radionuclides with a NaI(Tl) detector and gamma-ray spectrometer at intervals of 1, 2 and 5 hours after sampling.*(4)*

3.1.2 ***Radionuclide release.*** The permissible limits for Oyster Creek stack effluents have been established as follows by the AEC to assure conformance to Title 10 Code of Federal Regulations Part 20:

1. The maximum release rate of gross activity, except iodines and particulates with half-lives longer than eight days, shall be limited in accordance with the following equation:

   $$Q = 0.21/\bar{E} \text{ Ci/s}$$

   where Q is the stack release rate (Ci/s) of gross activity and $\bar{E}$ is the average gamma energy per disintegration (MeV/dis). (The nominal limit observed by the station is 0.26 Ci/s.*(3)*)
2. The maximum release rate of iodines and particulates with half-lives longer than eight days shall not exceed 4 μCi/s.
3. Radiogases released from the stack shall be continuously monitored except for the short time during monitor filter changes. If this specification cannot be met, the reactor shall be placed in the isolated condition.*(3)*

Gaseous waste discharges of radioactive noble gases, halogens, particles and tritium reported periodically by the station operator*(11)* are tabulated in Appendices B.2 and B.3. The station has reported the following annual discharges since reactor operation began:

	Annual discharge, Ci			
Year	Noble gases	Halogens	Particles	^3H
1969	7.0 x 10^5	3 x 10^{-1}*	8 x 10^{-4}	**
1970	1.1 x 10^6	3.1 x 10^{-1}*	1.0 x 10^{-2}	**
1971	5.2 x 10^5	2.0	1.7 x 10^{-1}†	**
1972	8.7 x 10^5	6.3	2.3 x 10^{-1}†	7.5 x 10^1
1973	8.1 x 10^5	6.7	4.2 x 10^{-1}	3.2 x 10^1

---

* Includes only halogens with half-lives greater than 8 d.

**Included with noble gas total.

† No alpha-emitting radionuclides detected.

3.1.3 *Sample collection.* Samples of off-gas from the main condenser SJAE were obtained at a point 4 minutes into the delay line on August 31, 1971, January 18, 1972, April 10 and 12, 1972, August 24, 1972, December 13, 1972 and March 28, 1973. All samples were obtained in duplicate. Samples were supplied by station personnel in 15-cc glass serum bottles (in 4-cc bottles for August 1971 samples) stoppled with rubber inserts and covered with sealing wax.

Stack effluent samples were collected in evacuated metal bottles from a port following the filter and cartridge in the stack air monitoring line. Samples collected were:

Date	Volume, liters	Date	Volume, liters
January 20, 1972	1.8	August 23, 1972	1.8
February 29, 1972	34.	December 13, 1972	8.2
April 10, 1972	1.8	March 28, 1973	34.
May 17, 1972 (during refueling)	34.		

Particulate air filters exposed in the stack monitor during 16 sampling periods ranging from July 1971 to December 1972 were obtained. Also provided were 17 charcoal cartridges representing essentially the same periods. These samples were provided by the station staff after they had completed their analyses that required several weeks, which precluded measurement of short-lived emissions. The sample of December 1972, however, was provided 6 days after removal.

Other samples included 34 liters of off-gas from the turbine gland seal condenser SJAE (February 29, 1972), 1.8 liters of air from the reactor drywell (April 11, 1972) and 34 liters of air exhausted through the ventilation ducts from each of the turbine, reactor and radwaste buildings (March 28, 1973).

As part of the joint study, the AEC Health and Safety Laboratory (HASL) obtained off-gas samples from the SJAE on August 31, 1971, February 29, 1972, April 10 and 12, 1972, and March 28, 1973.*(7,8)* To study variation of individual radionuclide concentrations, HASL obtained off-gas samples on the morning and afternoon of January 18 to 20 and morning of January 21, 1972. Their onsite measurements with a Ge(Li) detector and multichannel analyzer provided data on many short-lived gases. HASL has also reported results of gas samples obtained from the stack and the turbine gland seal condenser on February 19, 1972. HASL measurements are tabulated in Appendices D.1 to D.4.

3.2 Analysis

3.2.1 *Gamma-ray spectrometry.* Radionuclides that emit gamma-rays were routinely analyzed with a 10- x 10-cm NaI(Tl) detector coupled with a 400-channel pulse-height analyzer. Samples containing many radionuclides were analyzed with 11.3-cc or 55-cc Ge(Li) detectors and a 4096-channel pulse-height analyzer. Iron-55 was measured with a xenon-filled x-ray proportional counter and a 200-channel pulse-height analyzer.

Sample analyses were begun normally two to five days after collection, hence only radionuclides with relatively long half-lives were usually detectable. Off-gas from the steam condenser air ejectors was counted in the collection bottles. Aliquots of 1.8-, 8.2-, or 34-liter bottles were transferred to 209-cc glass flasks, sealed with rubber stoppers, aluminum bands and sealing compound. Particulate air filters and charcoal cartridges were placed directly on the detectors.

Detection efficiencies for the radionuclides, containers, sample volumes and media of interest were determined with standardized radioactive solutions and gases provided by the National Bureau of Standards. Because glass contains ^{40}K, and charcoal, ^{40}K and ^{226}Ra, distinct background measurements were made for these materials.

Counting intervals and techniques were selected to provide, when possible, analytical precision of ±10 percent or better at the 95-percent confidence level. The usual counting duration for low-level radioactivity was 1000 min. Samples were re-analyzed periodically to confirm container sealing integrity and radionuclide quantification and to look for longer-lived radionuclides.

Radionuclide decay scheme data were obtained from compilations provided by the Nuclear Data Project.*(12,13)*

3.2.2 *Radiochemical analysis.* Krypton-85 was separated from other gases by a cryogenic technique

(14) and transferred to 25-cc bottles containing 15 cc of 1-mm-dia. plastic scintillator spheres for analysis by a liquid scintillation counter. Approximately one half of the sample volume was used.

The other half of the gas sample was used for duplicate measurements of tritium as HTO vapor and HT or other gaseous forms and ^{14}C as CO_2 and other gaseous forms (CO, CH_4, etc.). Aliquots were mixed with radioactively pure H_2, CH_4, and CO_2 carrier gases and if necessary, water vapor. The mixture was passed through a separation train consisting sequentially of a −76° C freeze trap for removal of tritiated moisture, a bubbler containing $Ba(OH)_2$ to collect $^{14}CO_2$, an alumina-platinum (0.5 percent) catalyst heated to 750° C for oxidation of hydrogen (collected in a second freeze trap) or other ^{14}C gases (removed in a second bubbler with $Ba(OH)_2$). Tritium was measured by liquid scintillation counting for at least 300 min. Carbon-14 was determined by low background GM beta particle detectors and, for samples obtained after July 1972, by liquid scintillation counting.

Strontium was chemically separated from the particulate filters and measured with low background GM beta particle detectors for 100-min periods. Strontium-90 was distinguished from ^{89}Sr by separating and counting the ^{90}Y daughter.

3.3 Results and Discussion

3.3.1 *Gaseous radionuclides discharged from reactor coolant at main condenser steam jet air ejectors.* Radionuclides found in off-gas from the SJAE include, as given in Table 3.1, long-lived noble gases, gaseous ^3H, and ^{14}C, both as CO_2 and other gaseous carbon. Measurements by HASL of long-lived as well as many short-lived noble gases, ^{131}I and, on one occasion, ^{13}N are presented in Appendix D.1.*(7,8)* Included in the tables are the gross release rates of radioactive stack effluents at the time of sampling, as reported by the station operator or measured by HASL.

Average discharge rates and estimates of annual releases of radionuclides from the SJAE delay line are given in Table 3.2 (EPA measurements) and Appendix D.2 (HASL measurements). Average release rates during sampling were calculated by multiplying mean concentrations (last columns, Table 3.1 and Appendix D.1) by the delay line flow rate. To obtain representative annual discharges, the individual radionuclide release rates (Table 3.2, column 1) were normalized by the ratio of the gross radioactivity release rates during sampling (Table 3.1, last line) to 3.90 x 10^4 µCi/s, the average release rate during reactor operation from July 1, 1971 to June 30, 1973. Estimates of annual radionuclide discharges were based on 80 percent plant availability.

The SJAE off-gas delay line discharges to the stack about 1 x 10^6 Ci/yr, consisting almost entirely of noble gas radionuclides. Tritium and ^{14}C releases are on the order of 1 and 3 Ci/yr, respectively. Release of ^{13}N based on a single observation is estimated to be 500 Ci/yr.

Annual releases estimated from measurements compare as follows with values calculated from the source term for the AEC model BWR plant *(9)* and values presented in the station Environmental Report:*(2)*

Radionuclide		Annual discharge, Ci		
		Measured	Model BWR*(9)**	Station report*(2)***
1.86-hr	^{83m}Kr	---	3.1 x 10^4	---
4.48-hr	^{85m}Kr	6.9 x 10^4	6.9 x 10^4	8.8 x 10^4
10.7 -yr	^{85}Kr	1.1 x 10^2†	4.2 x 10^2	---
76.3-min	^{87}Kr	1.3 x 10^5	1.3 x 10^5	2.2 x 10^5
2.80-hr	^{88}Kr	1.4 x 10^5	2.0 x 10^5	3.0 x 10^5
3.16-min	^{89}Kr	---	0	---
11.9 -d	^{131m}Xe	---	3.7 x 10^2	---
2.25-d	^{133m}Xe	5.1 x 10^3†	5.0 x 10^3	---
5.29-d	^{133}Xe	1.6 x 10^5†	1.4 x 10^5	2.0 x 10^5
15.65-min	^{135m}Xe	8.8 x 10^4	1.6 x 10^4	---
9.15-hr	^{135}Xe	3.0 x 10^5†	3.8 x 10^5	3.3 x 10^5
3.83-min	^{137}Xe	---	2.2	---
14.17-min	^{138}Xe	6.0 x 10^4	4.5 x 10^4	7.6 x 10^4
8.06-d	^{131}I	1.7	8.3	---
20.9 -hr	^{133}I	---	4.5 x 10^1	---
Total		9.5 x 10^5	1.0 x 10^6	1.2 x 10^6

* Based on source term for a 3500 MWt reactor with 30 min SJAE off-gas delay normalized to 1930 MWt and 75 min delay.

**Applies for 32 days of steady operation at 1850 MWt, 60 min delay and a delay line flow rate of 5.3 x 10^4 cc/s.

† Average of values from Table 3.2 and Appendix D.2.

Annual discharges based on measurements agree very well with values computed from the AEC model, excepting ^{85}Kr, ^{135m}Xe and ^{131}I. Results from the station Environmental Report are consistently higher, which probably results from the choice of different operating parameters.

Estimated SJAE discharges provided in the AEC Environmental Statement*(6)* for Oyster Creek approximate those of the AEC Model BWR, except that ^{133m}Xe and ^{137}Xe releases are computed to be 500 and 29 Ci/yr. Estimates given by the EPA model*(10)* are very similar to the AEC model, although the ^{85}Kr discharge is calculated to be 240 Ci/yr.

Table 3.1 Concentrations of Longer-Lived Radioactive Gases Released from Main Condenser Steam Jet Air Ejectors

Radionuclide	Concentration,* µCi/cc							
	Aug. 31, 1971	Jan. 18, 1972	Apr. 10, 1972	Apr. 12, 1972	Aug. 24, 1972	Dec. 13, 1972	Mar. 28, 1973	Average**
^{3}H (gas)	NA	$2 \pm 1 \times 10^{-6}$	$2 \pm 1 \times 10^{-7}$	$3.9 \pm 0.7 \times 10^{-7}$	$< 3 \times 10^{-7}$	$4 \pm 1 \times 10^{-7}$	$6 \pm 2 \times 10^{-7}$	7×10^{-7}
^{3}H (H_2O)	NA	$< 1 \times 10^{-6}$	$< 2 \times 10^{-7}$	$< 9 \times 10^{-8}$	$< 3 \times 10^{-7}$	$< 1 \times 10^{-7}$	$< 5 \times 10^{-8}$	$< 3 \times 10^{-7}$
^{14}C (non-CO_2)	NA	$7.2 \pm 0.8 \times 10^{-6}$	$3.5 \pm 0.8 \times 10^{-7}$	$2.5 \pm 0.5 \times 10^{-7}$	$1.8 \pm 0.8 \times 10^{-7}$	$1.5 \pm 0.9 \times 10^{-7}$	$1.0 \pm 0.5 \times 10^{-7}$	1.4×10^{-6}
^{14}C (CO_2)	NA	$5.5 \pm 0.8 \times 10$-^{6}	$4.2 \pm 0.3 \times 10^{-6}$	$2.3 \pm 0.2 \times 10^{-6}$	$2.8 \pm 0.1 \times 10^{-6}$	$1.5 \pm 0.4 \times 10^{-6}$	$1.2 \pm 0.1 \times 10^{-7}$	2.7×10^{-6}
^{85}Kr	NA	NA	$9.9 \pm 0.1 \times 10^{-5}$	$2.7 \pm 0.1 \times 10^{-4}$	$2.2 \pm 0.1 \times 10^{-5}$	$3.0 \pm 0.2 \times 10^{-5}$	NA	7.9×10^{-5}
^{133m}Xe	$1.0 \pm 0.1 \times 10^{-2}$	$4.4 \pm 0.1 \times 10^{-3}$	$5.9 \pm 0.3 \times 10^{-3}$	$7 \pm 1 \times 10^{-3}$	$9.2 \pm 0.4 \times 10^{-4}$	$4.4 \pm 0.4 \times 10^{-4}$	$1.3 \pm 0.1 \times 10^{-2}$	5.7×10^{-3}
^{133}Xe	$2.7 \pm 0.1 \times 10^{-1}$	$1.0 \pm 0.1 \times 10^{-1}$	$1.4 \pm 0.1 \times 10^{-1}$	$1.3 \pm 0.1 \times 10^{-1}$	$2.3 \pm 0.1 \times 10^{-2}$	$6.7 \pm 0.1 \times 10^{-2}$	$3.1 \pm 0.1 \times 10^{-1}$	1.5×10^{-1}
^{135}Xe	$5.6 \pm 0.1 \times 10^{-1}$	$2.6 \pm 0.1 \times 10^{-1}$	NA	$3.9 \pm 0.1 \times 10^{-1}$	NA	NA	$7.1 \pm 0.1 \times 10^{-1}$	4.4×10^{-1}
Gross radioactivity release rate, µCi/s	3.6×10^{4}	4.7×10^{4}	7.8×10^{4}	7.8×10^{4}	1.4×10^{4}	4.0×10^{4}	1.2×10^{5}	---

* Concentration measured at beginning of the 75-min delay line.

**Average concentration computed for 75-min delay. Results of Apr. 10 and 12, 1972, were averaged as single sample.

Notes:

1. ± values indicate analytical error expressed at 2σ; < values are minimum detectable concentration levels at the 3σ counting error.
2. NA - not analyzed.

Table 3.2 Release Rates and Estimated Annual Discharges of Longer-Lived Radioactive Gases from Main Condenser Air Ejector Delay Line

Radionuclide	Average release rate during sampling,* μCi/s	Normalized avg. release rate,** μCi/s	Estimated annual release,† Ci
^{3}H (gas)	3.2×10^{-2}	2.1×10^{-2}	5.0×10^{-1}
^{3}H (H_2O)	$<1 \times 10^{-2}$	$<8 \times 10^{-3}$	$<2 \times 10^{-1}$
^{14}C (non-CO_2)	6.2×10^{-2}	4.0×10^{-2}	1.0
^{14}C (CO_2)	1.2×10^{-1}	8.0×10^{-2}	2.0
^{85}Kr	3.5	3.1	7.9×10^{1}
^{133m}Xe	2.6×10^{2}	1.8×10^{2}	4.6×10^{3}
^{133}Xe	6.7×10^{3}	4.7×10^{3}	1.2×10^{5}
^{135}Xe	2.0×10^{4}	1.1×10^{4}	2.8×10^{5}

* Based on a delay line off-gas flow rate of 4.5×10^{4} cc/s.

** Average of gross radioactivity stack release rates during sampling normalized to annual average stack release rate of 3.90×10^{4} μCi/s reported by station during operation in period of July 1, 1971 to June 30, 1973.

† Based on 292 d (2.52×10^{7} s) of reactor operation per year (80 percent availability).

Because of the good agreement between measured values and the AEC model, the latter may be useful for inferring discharges of those radionuclides not measured because they possess either weak energy emissions, low abundance or rapid decay rates. Of the four noble gases, ^{83m}Kr is the most abundant, being discharged at about 3×10^{4} Ci/yr.

3.3.2 *Radionuclides discharged from air ejector at turbine gland seal condenser.* Gaseous radionuclides with half-lives longer than 14 min were measurable in the single sample of gas from the condenser SJAE for gland seal steam. Concentrations of long-lived radionuclides are given in Table 3.3. Noble gas measurements by HASL are presented in Appendix D.3.

All radionuclides measured in off-gas from the main condensers were found in gland seal condenser off-gas. The latter, however, contained a higher percentage of short-lived radionuclides at the point of discharge to the stack due to a shorter holdup period. Gaseous tritium was not detectable in gland seal exhaust (the presence of tritiated water vapor is uncertain). Carbon-14 was measurable only as CO_2.

Radionuclide release rates to the stack and estimated annual discharge from this pathway are also given in Table 3.3 and Appendix D.3.

Annual releases calculated for Oyster Creek from the AEC model are as follows: *(6,9)*

^{83m}Kr	4.8×10^{1} Ci/yr	^{131m}Xe	6×10^{-1} Ci/yr
^{85m}Kr	8.0×10^{1}	^{133m}Xe	5
^{85}Kr	< 1	^{133}Xe	1.4×10^{2}
^{87}Kr	2.4×10^{2}	^{135m}Xe	3.8×10^{2}
^{88}Kr	2.6×10^{2}	^{135}Xe	4.1×10^{2}
^{89}Kr	6.2×10^{2}	^{137}Xe	1.1×10^{3}
^{131}I	2.3×10^{-2}	^{138}Xe	1.2×10^{3}
^{133}I	1.3×10^{-1}		

Calculated releases agree within a factor of two with measured values, except for ^{135m}Xe. The agreement indicates that the computed values may be used to infer releases of short-lived noble gases. Annual noble gas discharge from this pathway is of the order of 4.5×10^{3} Ci/yr, much less than one percent of that from the main condenser SJAE. Radioiodine releases from the gland seal system are indicated to be about 0.2 Ci/yr.

Gland seal steam flows nominally at 0.1 percent of the total steam flow (3.3×10^{6} kg/hr). Comparison of the release rate of relatively long-lived ^{133}Xe from the gland seal condenser to the rate computed from its measured concentration in main condenser SJAE off-gas for February 29, 1972 (see Appendix D.1) yields a result close to the nominal exhaust rate of 0.1 percent.

Table 3.3 Long-Lived Radioactive Gases from the Turbine Gland Seal Condenser Air Ejector, February 29, 1972

Radionuclide	Concentration, µCi/cc	Release rate,* µCi/s	Estimated annual release,**Ci
^{3}H (gas)	$< 3 \times 10^{-10}$	$< 8 \times 10^{-5}$	$< 2 \times 10^{-3}$
^{3}H (H_2O)	NA	---	---
^{14}C (non-CO_2)	$< 4 \times 10^{-10}$	$< 1 \times 10^{-4}$	$< 3 \times 10^{-3}$
^{14}C (CO_2)	$6 \pm 2 \times 10^{-10}$	2×10^{-4}	5×10^{-3}
^{85}Kr	$2.4 \pm 0.1 \times 10^{-8}$	6.7×10^{-3}	1.9×10^{-1}
^{133}Xe	$2 \pm 1 \times 10^{-5}$	6	2×10^{2}

* Based on an off-gas flow rate of 2.8×10^{5} cc/s (600 cfm).

**Calculated from the release rate by normalizing to the annual average stack release rate of 3.9×10^{4} µCi/s and multiplying by 292 d (2.52×10^{7} s) of operation. Stack release rate at sampling time was 3.5×10^{4} µCi/s.

Notes:

1. $\pm$ values indicate analytical error expressed at 2σ; < values are minimum detectable concentration levels at 3σ counting error.
2. NA - not analyzed.

Annual release of ^{13}N from gland seal leakage is calculated to be 5×10^{2} Ci. This estimate is based on the single HASL measurement of ^{13}N in main condenser SJAE off-gas (see Appendix D.1) corrected for decay to the beginning of the delay line, 0.1 percent steam flow, 1.75 min of delay, and a turbine gland seal SJAE flow rate of 2.8×10^{5} cc/s.

3.3.3 ***Radionuclides in building ventilation air exhaust.*** Xenon-135 was the most abundant long-lived radioactive gas measured in the single samples of air exhausted from the reactor, turbine and radwaste buildings, as shown in Table 3.4. Tritiated water vapor and ^{14}C as CO_2 were found in all samples. Turbine and radwaste building exhaust contained long-lived noble gases; only ^{85}Kr was detectable in reactor building exhaust. No radioiodines were detected in any sample. The minimum detectable concentration of ^{131}I, for example, in this case was $< 4 \times 10^{-8}$ µCi/cc at the 3 σ level.

Turbine building air bore the highest gaseous radioactivity, due presumably to more leakage of steam to air. Its annual discharge of long-lived gases is estimated to be 3×10^{3} Ci/yr, while the reactor and radwaste buildings contribute about 3 Ci/yr and 2×10^{3} Ci/yr, respectively.

Annual release values at the reactor building computed in the Oyster Creek Environmental Statement were 1 Ci/yr for individual noble gas radionuclides and 1.5×10^{-1} and 6.2×10^{-2} Ci/yr for ^{131}I and ^{133}I, respectively.*(6)* Turbine building discharge computed from the model contains all the noble gas radionuclides found in off-gas from the condenser SJAE (see Section 3.3.1). All nuclides, except ^{85}Kr and ^{131m}Xe, are exhausted at more than 1 Ci/yr, and the total is estimated to be 1.2×10^{3} Ci/yr.*(6)* Calculated emissions of ^{133}Xe and ^{135}Xe, however, are both 25 times lower than annual discharge estimated from measured concentrations (Table 3.4), indicating a higher steam leakage rate than the 770 kg/hr value assumed for the model. Iodine-131 and ^{133}I releases given by the model are 0.53 and 3.0 Ci/yr, respectively.

Radwaste building annual discharges are not estimated in the Environmental Statement. Values reported elsewhere by the station operator indicate that 1.9×10^{3} Ci/yr are released when the gross radioactivity release rate is 3.9×10^{4} µCi/s.*(3)*

Annual releases of ^{3}H based on measurements by HASL in 1972 are 2.0, 8.3 and 0.8 Ci/yr for reactor, turbine and radwaste building exhaust air, respectively.*(15)* The two sets of results agree within a factor of 3.

Additional sampling is recommended to obtain discharge rates representative of operating cycle variations, to obtain measurements of short-lived noble

Table 3.4 Long-Lived Radioactive Gases in Building Ventilation Air, March 28, 1973

Radionuclide	Concentration, μCi/cc	Release rate,* μCi/s	Estimated annual release,** Ci
Reactor Building			
^{3}H (gas)	$< 6 \times 10^{-11}$	$< 2 \times 10^{-3}$	$< 5 \times 10^{-2}$
^{3}H (H_2O)	$2.1 \pm 0.2 \times 10^{-9}$	6.4×10^{-2}	1.6
^{14}C (non-CO_2)	$< 6 \times 10^{-11}$	$< 2 \times 10^{-3}$	$< 5 \times 10^{-2}$
$^{14}CO_2$	$3.8 \pm 0.5 \times 10^{-10}$	1.2×10^{-2}	3.1×10^{-1}
^{85}Kr	$7.9 \pm 0.5 \times 10^{-10}$	2.4×10^{-2}	6.1×10^{-1}
^{133m}Xe	$< 8 \times 10^{-7}$	$< 2 \times 10^{1}$	$< 7 \times 10^{2}$
^{133}Xe	$< 8 \times 10^{-8}$	< 3	$< 7 \times 10^{1}$
^{135}Xe	$< 4 \times 10^{-7}$	$< 1 \times 10^{1}$	$< 3 \times 10^{2}$
Turbine Building			
^{3}H (gas)	$< 6 \times 10^{-11}$	$< 2 \times 10^{-3}$	$< 6 \times 10^{-2}$
^{3}H (H_2O)	$2.4 \pm 0.1 \times 10^{-8}$	9.4×10^{-1}	2.4×10^{1}
^{14}C (non-CO_2)	$< 5 \times 10^{-11}$	$< 2 \times 10^{-3}$	$< 6 \times 10^{-2}$
^{14}C (CO_2)	$8.7 \pm 0.3 \times 10^{-10}$	3.4×10^{-2}	8.5×10^{-1}
^{85}Kr	$1.4 \pm 0.1 \times 10^{-9}$	5.5×10^{-2}	1.4
^{133m}Xe	$< 3 \times 10^{-7}$	$< 1 \times 10^{1}$	$< 3 \times 10^{2}$
^{133}Xe	$7.9 \pm 0.6 \times 10^{-7}$	3.1×10^{1}	7.8×10^{2}
^{135}Xe	$2.4 \pm 0.2 \times 10^{-6}$	9.4×10^{1}	2.4×10^{3}
Radwaste Building			
^{3}H (gas)	$< 5 \times 10^{-11}$	$< 4 \times 10^{-4}$	$< 1 \times 10^{-2}$
^{3}H (H_2O)	$7.8 \pm 0.5 \times 10^{-9}$	5.7×10^{-2}	1.8
^{14}C (non-CO_2)	$< 5 \times 10^{-11}$	$< 4 \times 10^{-4}$	$< 1 \times 10^{-2}$
^{14}C (CO_2)	$1.4 \pm 0.4 \times 10^{-10}$	1.0×10^{-3}	3.2×10^{-2}
^{85}Kr	NA	---	---
^{133m}Xe	$< 4 \times 10^{-6}$	$< 3 \times 10^{1}$	$< 9 \times 10^{2}$
^{133}Xe	$9.8 \pm 0.4 \times 10^{-7}$	7.2	2.3×10^{2}
^{135}Xe	$7.1 \pm 0.3 \times 10^{-6}$	5.2×10^{1}	1.6×10^{3}

* Based on ventilation air exhaust rates: reactor building -31 m^3/s
turbine building -39 m^3/s
radwaste building- 7.3 m^3/s

**Computed for 292 d/yr (2.52×10^7 s) of reactor operation for the reactor and turbine buildings and 365 d (3.15×10^7 s) of radwaste operations.

Notes:

1. ± values are analytical error expressed at 2σ; < values are minimum detectable concentrations at 3σ.
2. NA - not analyzed.

gases and to measure discharges during operation of the turbine building roof exhausters.

3.3.4 *Radionuclides in reactor drywell air.* The single sample of drywell atmosphere contained ^{3}H as gas and water vapor, ^{14}C as CO_2, and noble gases with half-lives longer than two days, as shown in Table 3.5. Short-lived radionuclides could not be analyzed since three days elapsed between sampling and measurement. As indicated in Figure 2.2, the containment had not been purged for at least three months before the date of sampling.

Table 3.5 Long-Lived Radioactive Gases in the Reactor Drywell Atmosphere, April 11, 1972

Radionuclide	Concentration, μCi/cc	Estimated annual discharge,* Ci
^{3}H (gas)	$1.0 \pm 0.2 \times 10^{-8}$	1.7×10^{-4}
^{3}H (H_2O)	$4 \pm 1 \times 10^{-8}$	6×10^{-4}
^{14}C (non-CO_2)	$< 6 \times 10^{-9}$	$< 5 \times 10^{-5}$
^{14}C (CO_2)	$5.5 \pm 0.5 \times 10^{-8}$	9.6×10^{-4}
^{85}Kr	$1.6 \pm 0.1 \times 10^{-6}$	2.8×10^{-2}
^{133m}Xe	$7 \pm 2 \times 10^{-6}$	1×10^{-1}
^{133}Xe	$1.3 \pm 0.1 \times 10^{-4}$	2.2

*Based on a drywell free air volume of 8.64×10^{9} cc (305,000 ft^3) and two drywell purges per year.

Note:

1. ± values indicate analytical error expressed at 2σ; < values are minimum detectable concentrations at 3σ.

Annual discharge of measured gases, based on a free air volume of 8.64×10^{3} m^3 and two drywell purges per year, is estimated to be about 1.2 Ci/yr.

3.3.5 *Radionuclides in effluent from startup vacuum pumps.* Radioactive gases in effluent pumped from the main condensers during reactor startup were not measured. Annual release values computed with the AEC model BWR indicate that the only radionuclides discharged of significance are ^{133}Xe and ^{135}Xe,*(9)* resulting from iodine decay. For the Oyster Creek plant, these emissions are expected to be 1300 and 190 Ci/yr, respectively, when the pumps are operated 4 hrs per startup and for four startups per year.

3.3.6 *Radioactive gases discharged through the stack.* Gaseous stack effluents were sampled on six occasions during reactor operation and once during refueling. All long-lived radionuclides found in the various pathways leading to the stack were measurable, as shown in Table 3.6. Tritium, ^{14}C and ^{85}Kr were released in detectable quantities during refueling. Radionuclide release rates and estimated annual discharges during reactor operation and refueling are given in Table 3.7. Gross radioactivity release rates, given in Table 3.6, were reported by the station operator, except the values for January 20, 1972, and February 29, 1972, which were determined by HASL.

Measurements by HASL of short- and long-lived noble gas discharges on two occasions are given in Appendix D.4.*(7,8)* This table also compares release rates of noble gases at the end of the delay line for main condenser SJAE and in the stack, which shows that this pathway accounts for practically all stack radioactivity.

The averages of measured stack effluents were used to check some of the previously described measurements at the sources of the gases. The three most significant contributors (see Figure 3.1) were summed: (1) SJAE off-gas (Section 3.3.1), (2) turbine gland seal condenser off-gas (TGSC, Table 3.3), and (3) building ventilation air exhaust (BVA, Table 3.4). These compare to discharge values from stack samples (Table 3.7) as follows:

Radionuclide	Estimated annual release, Ci				
	SJAE	TGSC	BVA	Sum	Stack samples
^{3}H (gas)	5.0×10^{-1}	$< 2 \times 10^{-3}$	$< 6 \times 10^{-2}$	5.0×10^{-1}	8.9×10^{-1}
^{3}H (H_2O)	$< 2 \times 10^{-1}$	---	2.7×10^{1}	2.7×10^{1}	2.5×10^{1}
^{14}C (non-CO_2)	1.0	$< 3 \times 10^{-3}$	$< 6 \times 10^{-2}$	1.0	1.0
^{14}C (CO_2)	2.0	5×10^{-3}	1.2	3.2	8.1
^{85}Kr	1.1×10^{2}	1.9×10^{-1}	2.0	1.1×10^{2}	1.7×10^{2}
^{133m}Xe	5.1×10^{1}	5	---	5.1×10^{1}	6.7×10^{1}
^{133}Xe	1.6×10^{4}	2.1×10^{2}	1.0×10^{1}	1.6×10^{4}	1.2×10^{4}
^{135}Xe	3.0×10^{4}	4.7×10^{2}	4.0×10^{1}	3.0×10^{4}	3.5×10^{4}

All radionuclide pathway sums and stack results except ^{14}C agree within a factor of two. Only about one-third of $^{14}CO_2$ found in the stack samples was measured in the pathways, which may be attributable to low levels in building ventilation air at the time the single set of samples was obtained. It should be noted that a

Table 3.6 Concentrations of Long-Lived Radioactive Gases in Stack Effluent

Radionuclide	Concentration, μCi/cc						
	Jan. 20, 1972	Feb. 29, 1972	Apr. 10, 1972	May 17, 1972*	Aug. 23, 1972	Dec. 13, 1972	Mar. 28, 1973
^{3}H (gas)	<1 × 10^{-8}	<2 × 10^{-10}	<3 × 10^{-9}	3.7 ± 0.5 × 10^{-10} (total ^{3}H)	<8 × 10^{-9}	<5 × 10^{-10}	1.4 ± 0.2 × 10^{-9}
^{3}H (H_2O)	1.0 ± 0.6 × 10^{-8}	NA	1.9 ± 0.3 × 10^{-8}		3.7 ± 0.6 × 10^{-8}	1.0 ± 0.2 × 10^{-8}	2.0 ± 0.1 × 10^{-8}
^{14}C (non-CO_2)	<2 × 10^{-8}	<2 × 10^{-10}	<9 × 10^{-9}	2.5 ± 1.0 × 10^{-10} (total ^{14}C)	<3 × 10^{-9}	2.0 ± 0.4 × 10^{-9}	1.0 ± 0.6 × 10^{-10}
^{14}C (CO_2)	<1 × 10^{-8}	1.3 ± 0.5 × 10^{-9}	<1 × 10^{-8}		1.4 ± 0.2 × 10^{-8}	3.7 ± 0.5 × 10^{-9}	2.9 ± 0.1 × 10^{-9}
^{85}Kr	NA	8.0 ± 0.1 × 10^{-8}	1.2 ± 0.1 × 10^{-7}	2.5 ± 0.1 × 10^{-9}	5.2 ± 0.1 × 10^{-8}	7.6 ± 0.4 × 10^{-8}	3.2 ± 0.2 × 10^{-7}
^{131m}Xe	6 ± 2 × 10^{-6}	NA	7 ± 2 × 10^{-6}	NA	NA	<2 × 10^{-6}	1.0 ± 0.2 × 10^{-5}
^{133}Xe	8.9 ± 0.2 × 10^{-5}	1.1 ± 0.1 × 10^{-4}	8.7 ± 0.1 × 10^{-5}	<4 × 10^{-7}	3.2 ± 0.3 × 10^{-5}	4.4 ± 0.3 × 10^{-5}	1.8 ± 0.1 × 10^{-4}
^{135}Xe	NA	NA	NA	NA	NA	NA	5.4 ± 0.2 × 10^{-4}
Gross radioactivity release rate, μCi/s	4.7 × 10^{4}	3.5 × 10^{4}	7.8 × 10^{4}	0	1.4 × 10^{4}	4.0 × 10^{4}	1.2 × 10^{5}

*Obtained during reactor refueling.

Notes:

1. ± values indicate analytical error expressed at 2σ; < values are minimum detectable concentration levels at the 3σ counting error.
2. NA - not analyzed.

Table 3.7 Release Rates and Estimated Annual Discharge of Long-Lived Radioactive Gases in Stack Effluent

Radionuclide	Average release rate,* µCi/s reactor operation**	 refueling	Estimated annual release,+ Ci reactor operation	 refueling	 total
^{3}H (gas)	3.5×10^{-2}	2.9×10^{-2} (total ^{3}H)	8.9×10^{-1}	1.2×10^{-1}	8.9×10^{-1}
^{3}H (H_2O)	9.8×10^{-1}		2.5×10^{1}		2.5×10^{1}
^{14}C (non-CO_2)	4.0×10^{-2}	1.9×10^{-2} (total ^{14}C)	1.0	8.4×10^{-2}	1.0
^{14}C (CO_2)	3.2×10^{-1}		8.1		8.1
^{85}Kr	6.9	2.0×10^{-1}	1.7×10^{2}	8.4×10^{-1}	1.7×10^{2}
^{133m}Xe	3×10^{2}	---	7×10^{3}	---	7×10^{3}
^{133}Xe	4.9×10^{3}	$< 3 \times 10^{1}$	1.2×10^{5}	$< 1 \times 10^{2}$	1.2×10^{5}
^{135}Xe	1.4×10^{4}	---	3.5×10^{5}	---	3.5×10^{5}

* Based on a stack flow rate of 77.9 m^3/sec (165,000 cfm)and average measured concentrations in Table 3.6.

**Average of gross radioactivity release rates during sampling normalized to annual average release rate of 3.90×10^{4} µCi/s reported by plant for period of July 1, 1971 to June 30, 1973.

+ Estimates based on 292 days (2.52×10^{7} s) of reactor operation and 50 days (4.32×10^{6} s) for refueling.

proper test of agreement requires that all pathways be sampled at the same time.

3.3.7 *Radioactive particles discharged through the stack.* Particulate radionuclides in stack effluents, given in Table 3.8, consisted of those found in reactor coolant (see Table 2.1). Most were long-lived fission and activation products; on occasion radionuclides with half-lives of a day to several days were measured when the interval between sampling and analysis was relatively short. The principal source of particulate radioactivity at Oyster Creek is reported to be unfiltered air exhausted from the reactor, turbine and radwaste buildings.*(15)*

Table 3.9 provides average concentrations and release rates of the sampled radionuclides and estimated annual discharge. Particle collection was assumed to proceed at a constant rate during the approximately 3-day exposure of each sample. Halves of the 10 samples collected in January 1972 were composited for analyses since several bore no identification. The principal radionuclides released as particles are ^{140}Ba, ^{239}Np and the radioiodines, ^{131}I and ^{133}I (radioiodines are discussed in Section 3.3.8). Annual releases of the longer-lived radionuclides were computed for 365 days of discharge per year, since release of particulate radionuclides in ventilation air

Table 3.8 Concentrations of Longer-Lived Particulate Radionuclides in Stack Effluent

Radionuclide	Concentration, µCi/m³ July 12-15, 1971	 July 24-27, 1971	 July 27-30, 1971	 Jan. 1-Feb. 1, 1972*	 Aug. 15-18, 1972	 Aug. 18-21, 1972	 Dec. 12-15, 1972**
27.7 -d ^{51}Cr	$< 5 \times 10^{-7}$	$< 5 \times 10^{-7}$	5.0×10^{-6}	1.6×10^{-7}	2.2×10^{-5}	3.8×10^{-6}	4.0×10^{-4}
313 -d ^{54}Mn	1.8×10^{-7}	5.0×10^{-8}	1.2×10^{-7}	6.4×10^{-7}	1.9×10^{-6}	7.0×10^{-7}	8.9×10^{-5}
2.7 -yr ^{55}Fe	1.3×10^{-6}	2.9×10^{-7}	1.7×10^{-6}	NA	1.9×10^{-5}	5.4×10^{-6}	4.8×10^{-4}
44.6 -d ^{59}Fe	$< 1 \times 10^{-7}$	$< 1 \times 10^{-7}$	$< 1 \times 10^{-7}$	2.7×10^{-7}	1.5×10^{-6}	2.5×10^{-7}	$< 9.5 \times 10^{-6}$
71.3 -d ^{58}Co	1.4×10^{-7}	3×10^{-8}	1.3×10^{-7}	1.9×10^{-7}	3.3×10^{-6}	7.0×10^{-7}	5.1×10^{-5}
5.26-yr ^{60}Co	4.6×10^{-7}	1.3×10^{-7}	5.0×10^{-7}	1.7×10^{-6}	3.3×10^{-6}	1.4×10^{-6}	3.5×10^{-4}
50.5 -d ^{89}Sr	9.8×10^{-7}	2.4×10^{-6}	1.3×10^{-5}	NA	1.5×10^{-5}	2.1×10^{-5}	NA
28.5 -yr ^{90}Sr	1.0×10^{-7}	4.1×10^{-8}	8.0×10^{-8}	NA	8.4×10^{-8}	6.6×10^{-8}	NA
66.2 -hr ^{99}Mo	NA	NA	NA	NA	2.8×10^{-5}	3.9×10^{-6}	5.2×10^{-4}
8.06-d ^{131}I	6.3×10^{-6}	2.5×10^{-6}	6.8×10^{-6}	2.9×10^{-5}	9.4×10^{-6}	1.8×10^{-5}	1.6×10^{-2}
2.07-yr ^{134}Cs	7.1×10^{-8}	1.5×10^{-7}	7.0×10^{-8}	5.8×10^{-8}	5.8×10^{-7}	4.4×10^{-7}	1.9×10^{-4}
30.0 -yr ^{137}Cs	4.2×10^{-7}	3.6×10^{-7}	2.4×10^{-7}	2.2×10^{-7}	9.5×10^{-7}	9.9×10^{-7}	3.7×10^{-4}
12.8 -d ^{140}Ba	1.1×10^{-5}	3.1×10^{-6}	1.2×10^{-5}	5.0×10^{-6}	9.0×10^{-6}	1.5×10^{-5}	2.3×10^{-3}
32.8 -d ^{141}Ce	4.3×10^{-7}	1.5×10^{-7}	5.9×10^{-7}	1.7×10^{-7}	$< 4.0 \times 10^{-8}$	$< 3.0 \times 10^{-8}$	5.6×10^{-5}

* Measurement of composite set of 10 filters.

**Also measured, in µCi/m³: 244-d ^{65}Zn - 2.4×10^{-5}, 20.9-hr ^{133}I - 1.6×10^{-2}, 13-d ^{136}Cs - 2.3×10^{-5}, and 2.34-d ^{239}Np - 3.5×10^{-3}.

Note: NA - not analyzed.

Table 3.9 Average Concentration and Release Rates and Estimated Annual Discharge of Longer-Lived Particulate Radionuclides from Stack

Radionuclide	Average concentration,[*] μCi/m^3	Average release rate[**] μCi/s	Estimated annual discharge,[+] Ci
^{51}Cr	1.0 x 10^{-4}	8.0 x 10^{-3}	2.5 x 10^{-1}
^{54}Mn	2.3 x 10^{-5}	1.8 x 10^{-3}	5.7 x 10^{-2}
^{55}Fe	1.7 x 10^{-4}	1.3 x 10^{-2}	4.1 x 10^{-1}
^{59}Fe	3.3 x 10^{-6}	2.6 x 10^{-4}	8.2 x 10^{-3}
^{58}Co	1.3 x 10^{-5}	1.0 x 10^{-3}	3.2 x 10^{-2}
^{60}Co	8.7 x 10^{-5}	6.8 x 10^{-3}	2.1 x 10^{-1}
^{65}Zn	2.4 x 10^{-5}[++]	1.9 x 10^{-3}	6.0 x 10^{-2}
^{89}Sr	1.3 x 10^{-5}	1.0 x 10^{-3}	3.2 x 10^{-2}
^{90}Sr	7.4 x 10^{-8}	5.8 x 10^{-6}	1.8 x 10^{-4}
^{99}Mo	2.7 x 10^{-4}	2.1 x 10^{-2}	5.3 x 10^{-1}
^{131}I	3.9 x 10^{-3}	3.0 x 10^{-1}	9.5
^{133}I	1.6 x 10^{-2}[++]	1.2	3.0 x 10^{1}
^{134}Cs	4.9 x 10^{-5}	3.8 x 10^{-3}	1.2 x 10^{-1}
^{136}Cs	2.3 x 10^{-5}[++]	1.8 x 10^{-3}	5.7 x 10^{-2}
^{137}Cs	9.5 x 10^{-5}	7.4 x 10^{-3}	2.3 x 10^{-1}
^{140}Ba	5.8 x 10^{-4}	4.5 x 10^{-2}	1.4
^{141}Ce	1.9 x 10^{-5}	1.5 x 10^{-3}	4.7 x 10^{-2}
^{239}Np	3.5 x 10^{-3}[++]	2.7 x 10^{-1}	6.8

[*] Mean of the average concentrations for the July 1971, Jan. 1972, Aug. 1972 and Dec. 1972 sampling periods, given in Table 3.8, except as noted.

[**] Computed for a stack flow rate of 77.9 m^3/s.

[+] Estimate based on 365 days (3.15 x 10^7 s) of stack discharge for longer-lived radionuclides and 292 days for short-lived ^{99}Mo, ^{133}I and ^{239}Np.

[++] From single sample of Dec. 12-15, 1972.

was found to continue during purging and refueling operations.*(15)* Approximately 50 Ci of particulate radionuclides with half-lives longer than approximately one day were estimated to be discharged annually.

3.3.8 ***Radioiodines discharged through the stack.*** Concentrations and release rates of ^{131}I measured on 17 occasions with the charcoal stack sampler are given in Table 3.10. Release rates varied from 0.12 to 0.49 μCi/s during the observations. The mean release rate obtained from the averages for the five individual sampling periods is 0.30 μCi/s.

The annual ^{131}I discharge from charcoal measurement is estimated to be 7.6 Ci for 292 d of reactor operation. As indicated in Section 3.3.7, however, slightly more than this annual amount of ^{131}I was found on the particle sampler preceding the charcoal — presumably gaseous radioiodine entrained with particles. Summing these, the overall ^{131}I discharge is 17 Ci/yr. Since the SJAE is the expected major source of ^{131}I to the stack, it is difficult to explain the low amount measured (1.7 Ci/yr) relative to that in the stack. Although the AEC model BWR predicts five times more ^{131}I by the SJAE pathway (see Section

Table 3.10 Gaseous Iodine-131 Concentrations and Release Rates in Stack Effluents

Period	Concentration, μCi/m³*	Release rate,** μCi/s
July 12-15, 1971	2.0×10^{-3}	1.5×10^{-1}
24-27	1.7×10^{-3}	1.4×10^{-1}
27-30	1.6×10^{-3}	1.2×10^{-1}
Jan. 1- 4, 1972	3.1×10^{-3}	2.4×10^{-1}
4- 7	2.7×10^{-3}	2.1×10^{-1}
7-10	3.2×10^{-3}	2.5×10^{-1}
10-13	2.8×10^{-3}	2.2×10^{-1}
13-16	3.3×10^{-3}	2.6×10^{-1}
16-19	3.1×10^{-3}	2.4×10^{-1}
19-22	2.7×10^{-3}	2.1×10^{-1}
22-25	2.7×10^{-3}	2.1×10^{-1}
25-29	3.0×10^{-3}	2.3×10^{-1}
Jan. 29-Feb. 1	4.4×10^{-3}	3.5×10^{-1}
Apr. 7-11	3.3×10^{-3}	2.5×10^{-1}
Aug. 15-18	6.3×10^{-3}	4.9×10^{-1}
18-21	6.1×10^{-3}	4.7×10^{-1}
Dec. 12-15	5.0×10^{-3}	3.9×10^{-1}

* Analytical precision of all samples is 0.1 percent or less at the 2σ confidence level. Retention efficiency of cartridge assumed to be 90 percent.

**Computed for a stack flow rate of 77.9 m³/s (165,000 cfm).

3.3.1),*(9)* this will not account for all of the difference since the other pathways will contribute only small additional amounts (see Sections 3.3.2 and 3.3.3).

The AEC has reported that, based on a single set of measurements at Oyster Creek, most radioiodines were found to be discharged to the stack from the SJAE pathway, with lesser amounts from building ventilation exhaust.*(7,15)* The AEC indicated further that nearly all of the iodine was of an organic species. The remainder consisted of hypoiodous acid and a small fraction of elemental iodine. The ratios of other iodine radionuclide activities to ^{131}I in the stack were measured to be:

2.3-hr ^{132}I - 0.24
20.9-hr ^{133}I - 0.73
52.0-min ^{134}I - 0.29
6.7-hr ^{135}I - 0.38

Additional sampling at Oyster Creek is necessary to determine the pathways of all iodine radionuclides to the stack and their chemical composition.

3.3.9 ***Estimated annual radionuclide discharges.*** The effluent values discussed in the preceding parts of Section 3.3 provide the radioactivity source terms for planning environmental measurements. The total discharged radioactivity and the associated radiation doses (discussed in Section 3.3.10) based on estimates from measured values are as follows:

Radionuclide		Estimated annual release,* Ci	Estimated annual dose at location of highest annual concentration,** mrem
Gases			
12.3 -yr	^{3}H (as HT)	8.9×10^{-1}	4.2×10^{-7}
	(as HTO)	2.7×10^{1}	3.9×10^{-5}
5730. -yr	^{14}C (total)	9.1	8.7×10^{-4}
10. -min	^{13}N	$1. \times 10^{3}$	$7. \times 10^{-2}$
1.86-hr	^{83m}Kr	3.1×10^{4}†	1.2×10^{-1}
4.48-hr	^{85m}Kr	6.9×10^{4}	6.6×10^{-2}
10.7 -yr	^{85}Kr	1.7×10^{2}	5.4×10^{-5}
76.3 -min	^{87}Kr	1.3×10^{5}	6.2×10^{-1}
2.80-hr	^{88}Kr	1.4×10^{5}	4.5×10^{-1}
3.16-min	^{89}Kr	8.3×10^{2}†	3.2×10^{-3}
11.9 -d	^{131m}Xe	3.7×10^{2}†	8.8×10^{-5}
2.25-d	^{133m}Xe	5.1×10^{3}	1.6×10^{-3}
5.29-d	^{133}Xe	1.6×10^{5}	5.1×10^{-2}
15.65-min	^{135m}Xe	8.9×10^{4}	3.4×10^{-1}
9.15-hr	^{135}Xe	3.0×10^{5}	2.9×10^{-1}
3.83-min	^{137}Xe	1.5×10^{3}†	5.7×10^{-3}
14.17-min	^{138}Xe	6.2×10^{4}	2.4×10^{-1}
Particles and ^{131}I			
27.7 -d	^{51}Cr	2.5×10^{-1}	9.0×10^{-7}
313. -d	^{54}Mn	5.7×10^{-3}	1.6×10^{-5}
2.7 -yr	^{55}Fe	4.1×10^{-1}	3.9×10^{-4}
44.6 -d	^{59}Fe	8.2×10^{-3}	1.2×10^{-4}
71.3 -d	^{58}Co	3.2×10^{-2}	4.7×10^{-4}
5.26-yr	^{60}Co	2.1×10^{-1}	2.0×10^{-4}
244. -d	^{65}Zn	6.0×10^{-2}	6.8×10^{-4}
50.5 -d	^{89}Sr	3.2×10^{-2}	1.9×10^{-5}
28.5 -yr	^{90}Sr	1.8×10^{-4}	1.0×10^{-5}
2.76-d	^{99}Mo	6.6×10^{-1}	2.7×10^{-5}
8.06-d	^{131}I	1.7×10^{1}	3.2×10^{-2}
2.07-yr	^{134}Cs	1.2×10^{-1}	8.5×10^{-5}
13. -d	^{136}Cs	5.7×10^{-2}	2.7×10^{-4}
30.0 -yr	^{137}Cs	2.3×10^{-1}	1.3×10^{-4}
12.8 -d	^{140}Ba	1.4	4.0×10^{-4}
32.8 -d	^{141}Ce	4.7×10^{-2}	2.7×10^{-4}
2.34-d	^{239}Np	8.5	1.2×10^{-4}

* Except for ^{3}H (as HT), ^{14}C (as CO_2) and ^{85}Kr, the annual release represents the sum of the pathways; annual release of the former radionuclides are based on stack measurements. Values apply for an average stack release rate of 3.9×10^{4} μCi/s of gross radioactivity.

**Dose to critical organ specified in Appendix F.1.

† Calculated release, not directly measured.

Because these release values are based on occasional — sometimes single — measurements, they can only approximate the total discharges. Whether they are representative was checked by comparing: (1) measurement of the same pathway at several points, as in Section 3.3-6; (2) discharge data reported by the station for the semi-annual periods from July 1971 to June 1973 (see Appendices B.2 and B.3); and (3) discharge estimates in the Final Environmental Statement.*(6)* The latter two are as follows:

	Annual discharge, Ci	
Radio-nuclide	Oyster Creek reports	Environmental Statement estimate
^{3}H	5.1 x 10^{1}	---
^{83m}Kr	---	3.4 x 10^{4}
^{85m}Kr	7.4 x 10^{4}	6.9 x 10^{4}
^{85}Kr	---	4.2 x 10^{2}
^{87}Kr	1.4 x 10^{5}	1.4 x 10^{5}
^{88}Kr	2.1 x 10^{5}	2.0 x 10^{5}
^{89}Kr	---	8.3 x 10^{3}
^{131m}Xe	---	3.6 x 10^{3}
^{133m}Xe	---	5.0 x 10^{3}
^{133}Xe	1.1 x 10^{6}	1.4 x 10^{6}
^{135m}Xe	---	3.0 x 10^{4}
^{135}Xe	2.6 x 10^{5}	3.8 x 10^{5}
^{137}Xe	---	1.5 x 10^{5}
^{138}Xe	6.9 x 10^{4}	1.1 x 10^{5}
^{131}I	6.2	1.2 x 10^{1}
^{133}I	7.3	6.6 x 10^{1}

Annual noble gas discharges estimated from measurements agree with station reports. The values in the Environmental Statement are similar except that these predicted quantities are two-fold higher for ^{85}Kr and ^{135m}Xe than measured values, and 10-fold lower for ^{131m}Xe. The Environmental Statement estimates for ^{131m}Xe and ^{133m}Xe, however, differ considerably with AEC model BWR*(9)* values from which they are derived. Radioiodine releases reported by the station operator are lower than the estimates based on measurements in this study or given in the Environmental Statement. Estimated ^{3}H discharge from measurements is much higher than the reported station release; it is not certain whether the station measures ^{3}H discharge as HT, HTO or both.

The measurements show the predominant source of gaseous radionuclides found in the stack to be off-gas from the main condenser SJAE. Most tritiated water vapor, however, comes from steam leaks in the turbine building. Based on AEC model BWR values,*(9)* practically all short-lived ^{89}Kr and ^{137}Xe results from turbine gland seal exhaust.

3.3.10 *Estimated maximum radiation dose to individuals.* The annual total-body dose to an adult residing where the highest annual average concentration occurs (2.4 km north of the stack)*(2)* is estimated to be 2.3 millirems (mrem) from airborne effluents according to the values listed in Section 3.3.9. Practically all of the dose resulted from radioactive noble gases. Only about 0.1 percent of this dose was to specific organs from inhaling ^{131}I and airborne radioactive particles, and nearly all of this results from ^{131}I. The annual thyroid dose from inhaling ^{131}I at the maximum ratio of dose to intake — for a 4-year-old — would be four times the listed value, i.e., 0.13 mrem.*(10)* Additional dose increments would be expected from exposure to particulate progeny of noble gases (^{88}Rb, ^{138}Cs) and other iodine radionuclides. On the other hand, actual dose to persons would be lower since no adjustment was made for residential shielding and occupancy factors.

The annual dose for each listed radionuclide was obtained by computing the annual average concentration in ground-level air at the point of interest and then converting from concentration in air to tissue dose. To determine the average concentration at ground level, the estimated annual discharge was divided by 3.15 x 10^{7} s/yr to obtain the average discharge rate. This rate was multiplied by the annual average χ/Q (see Appendix E.3). The χ/Q values for various locations and distances were calculated by the station operator, using meteorological data compiled during a 12-month period.*(2)* The conversion factors from annual average radionuclide concentrations in ground-level air to the annual dose to specific critical organs are given in Appendix F.1.

The radiation dose at the nearest residence and other significant locations listed in Appendix E.3 relative to the maximum average ground-level concentration are:

Location	Distance and direction	Ratio of annual dose to dose at maximum location
nearest residence	1.1 km N	0.17
nearby population group	2.4 km ESE	0.91
nearby population group	2.4 km NNE	0.64
fishing in canal	0.8 km ESE	0.05

The relative dose to persons fishing in the coolant water discharge canal is based on 700 hrs of fishing per year.

3.4 References

1. Jersey Central Power and Light Co., "Facility Description and Safety Analysis Report, Oyster Creek Nuclear Power Plant," Vol. 1 and 2, USAEC Docket No. 50–219–1 and 50–219–2, Morristown, N. J. (1967).

2. Jersey Central Power and Light Co., "Oyster Creek Nuclear Generating Station – Environmental Report," Amend. No. 2, Morristown, N. J. (1972).

3. Jersey Central Power and Light Co., "Proposed Modification to the Gaseous Radioactive Waste System for Oyster Creek Nuclear Generating Station," Morristown, N. J. (1973).

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4. RADIONUCLIDES IN LIQUID WASTES

4.1 Liquid Waste Systems

4.1.1 *Waste processing.(1)* At the Oyster Creek station, four categories of radioactive liquid waste are segregated and processed according to source: low conductivity wastes, high conductivity wastes, chemical wastes, and laundry wastes (sometimes called detergent wastes). The source of liquid waste and the liquid waste processing systems, at the time of the study, are shown in Figure 4.1.

Low conductivity wastes are high purity liquids, primarily from piping and equipment drains. Other sources include liquid waste from the fuel pool, reactor cleanup system, adsorption chambers, spent resin and filter sludge dewatering, low conductivity condensate demineralizer backwash, and the chemical waste control subsystem. The liquid is transferred from the initial collection points to the 114,000-liter waste collector tank. Liquid from the waste collector tank is processed through a precoat-type waste collector filter and a mixed-bed waste demineralizer. Spent filter media and demineralizer resins are backwashed to the solid waste disposal system for solidification and shipment off-site for disposal. The processed liquid is collected in one of two 114,000-liter waste sample tanks. The liquid is sampled and analyzed for radioactivity before either (1) return for further processing, (2) transfer to the condensate storage tank, or (3) discharge to the circulating water discharge canal. The system is designed to process about 190,000 liters/day, providing approximately one day of decay time for liquids passing through at that rate.

High conductivity wastes are low purity liquids primarily from floor drains. The liquid is transferred

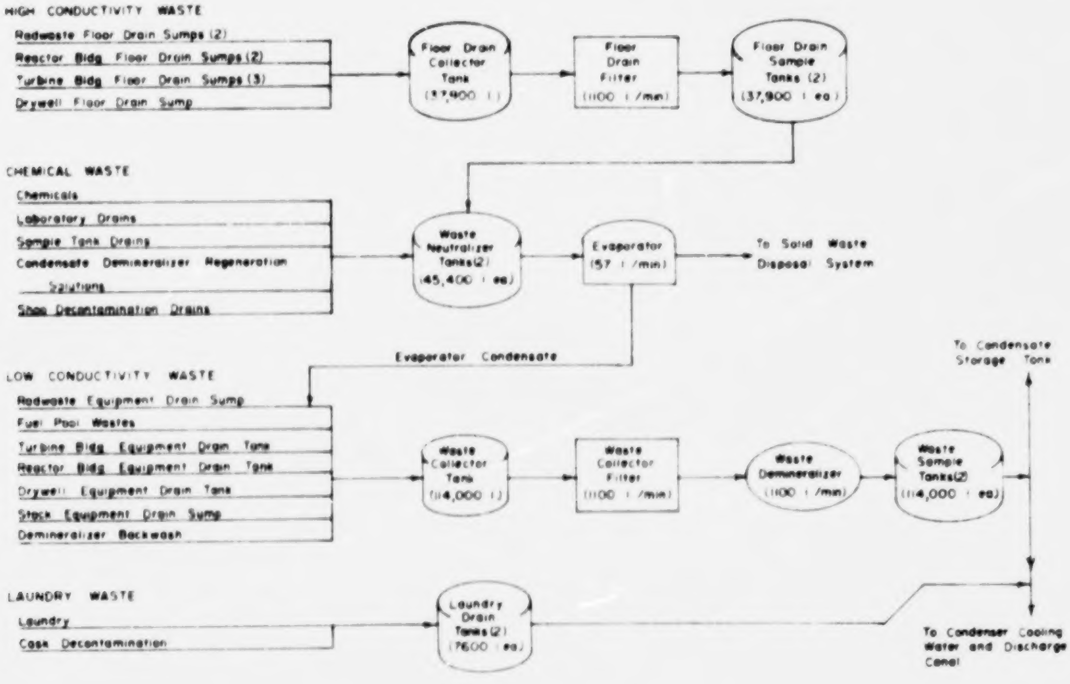
HIGH CONDUCTIVITY WASTE
Radwaste Floor Drain Sumps (2)
Reactor Bldg Floor Drain Sumps (2)
Turbine Bldg Floor Drain Sumps (3)
Drywell Floor Drain Sump
Floor Drain Collector Tank (37,900 l)
Floor Drain Filter (1100 l/min)
Floor Drain Sample Tanks (2) (37,900 l ea)
CHEMICAL WASTE
Chemicals
Laboratory Drains
Sample Tank Drains
Condensate Demineralizer Regeneration Solutions
Shop Decontamination Drains
Waste Neutralizer Tanks(2) (45,400 l ea)
Evaporator (57 l/min)
To Solid Waste Disposal System
Evaporator Condensate
LOW CONDUCTIVITY WASTE
Radwaste Equipment Drain Sump
Fuel Pool Wastes
Turbine Bldg Equipment Drain Tank
Reactor Bldg Equipment Drain Tank
Drywell Equipment Drain Tank
Stack Equipment Drain Sump
Demineralizer Backwash
Waste Collector Tank (114,000 l)
Waste Collector Filter (1100 l/min)
Waste Demineralizer (1100 l/min)
Waste Sample Tanks(2) (114,000 l ea)
To Condensate Storage Tank
LAUNDRY WASTE
Laundry
Cask Decontamination
Laundry Drain Tanks (2) (7600 l ea)
To Condenser Cooling Water and Discharge Canal

Figure 4.1 Liquid radioactive waste system.

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from collection sumps to the 37,900-liter floor drain collector tank in the radwaste building. From the tank the liquid is processed through a precoat-type floor drain filter and collected in one of two 37,900-liter floor drain sample tanks. The liquid is transferred from the floor drain sample tanks to a waste neutralizer tank for processing with chemical wastes. At a processing rate of 30,000 liters/day, approximately 3.5 days of decay time are provided for the high conductivity liquid waste.

Chemical wastes consist of laboratory drainage and condensate demineralizer regeneration solutions which have high conductivities and variable concentrations of radioactive material. The wastes are collected in one of two 45,400-liter waste neutralizer tanks along with the waste transferred from the floor drain sample tanks. The liquid collected in the waste neutralizer tanks is sampled for analysis, then neutralized and processed through the evaporator at a rate of 57 liters/min. The condensate from the waste concentrator is routed to the radwaste equipment drain sump for processing as low conductivity waste. A flow rate of 7,000 liters/day through the system would provide a decay time of 3.5 days for the chemical waste.

Laundry waste from the laundry operation and waste from the shipping cask decontamination station are collected in one of two 7,600-liter laundry drain tanks. These wastes are discharged to the circulating water discharge canal without treatment. Flow through this system is assumed by the AEC to be 3,000 liters/day.*(1)*

4.1.2 *Radionuclide release.* Radionuclide liquid release limits for the Oyster Creek station are based on the following:*(2)*

1. The release of radioactive liquid effluents shall be limited such that the concentration of radionuclides in the discharge canal at the site boundary shall not at any time exceed the concentrations given in Appendix B, Table II, Column 2, of 10 CFR 20 and notes 1 through 5 thereto.
2. Radioactive liquid effluent being released into the discharge canal shall be continuously monitored, or, if the monitor is inoperative, two independent samples of any tank to be discharged shall be taken, one prior to discharge and one near the completion of discharge, and two station personnel shall independently check valving prior to discharge of radioactive liquid effluents.

The radionuclides discharged in liquid waste from the Oyster Creek station between 1971 and 1973 are tabulated in Appendix B.4 and summarized in Table 4.1. The average concentration of radionuclides in the discharge canal due to station releases can be calculated from dilution volumes (see Table 4.1) as follows:

1971: uCi/ml = amount released (Ci/yr) x 9.5 x 10[illegible]
1972: uCi/ml = amount released (Ci/yr) x 8.6 x 10[illegible]
1973: uCi/ml = amount released (Ci/yr) x 8.4 x 10[illegible]

The limits in the discharge canal for an annual flow of 1.1 x 10^{15} ml and based on the limits listed in Appendix B, Table II, column 2 of 10 CFR 20 are tabulated in Table 4.1 with the radionuclide discharges.

Table 4.1 Radionuclides Discharged in Liquid Waste, Ci/yr

Radionuclide	1971	1972	1973	Limit,* Ci/yr
^{3}H	21.45	61.62	36.60	3 x 10^{6}
^{51}Cr	0.164	0.118	0.489	2 x 10^{6}
^{54}Mn	0.431	0.630	0.172	1 x 10^{5}
^{58}Co	0.108	0.153	0.043	1 x 10^{5}
^{60}Co	0.823	1.676	0.272	5 x 10^{4}
^{59}Fe	0.045	0.020	0.001	7 x 10^{4}
^{65}Zn	NR	NR	0.001	1 x 10^{4}
^{89}Sr	0.343	0.228	0.182	1 x 10^{4}
^{90}Sr			0.028	1 x 10^{2}
^{91}Sr	0.050	0.065	0.002	8 x 10^{4}
^{99}Mo	0.129	0.215	0.243	4 x 10^{4}
^{99m}Tc	0.101	0.199	0.242	3 x 10^{6}
^{124}Sb	0.003	0.003	NR	2 x 10^{4}
^{131}I	0.382	0.452	0.082	2 x 10^{3}
^{133}I	0.291	0.414	0.078	8 x 10^{3}
^{133}Xe	NR	0.784	0.754	---
^{135}Xe	NR	2.487	2.221	---
^{134}Cs	0.101	2.062	0.083	1 x 10^{4}
^{137}Cs	0.242	3.047	0.082	2 x 10^{4}
^{140}Ba-La	0.160	0.067	0.147	2 x 10^{4}
^{141}Ce	NR	NR	0.005	1 x 10^{5}
^{144}Ce	NR	NR	0.020	1 x 10^{4}
^{239}Np	0.656	0.683	0.233	1 x 10^{5}
Waste volume, 10^{7} liters	2.40	1.58	1.24	
Dilution volume, 10^{12} liters	1.05	1.16	1.19	

*Discharge into circulating cooling water flowing at the rate of 1.1 x 10^{15} ml/yr and permissible concentrations from Table II, Column 2, 10 CFR 20.

Note: NR - not reported.

The individual radionuclides were discharged at concentrations at or below 0.1 percent of these limits.

4.2 Samples and Analyses

4.2.1 *Samples*. The following samples of liquid waste were provided by the station staff:

1) waste sample tank "A", 1 liter, acidified, collected Aug. 30, 1971 at 0830;
2) waste sample tank "A", 1 liter, acidified, collected Jan. 18, 1972 at 0840;
3) waste sample tank "A", 500 ml, collected Jan. 18, 1972 at 0840;
4) waste sample tank "A", 1 liter, acidified, collected Mar. 2, 1972;
5) waste sample tank "A", 500 ml, acidified, collected April 12, 1972;
6) waste sample tank "A", 500 ml, collected April 12, 1972;
7) waste sample tank "A", 1 liter, collected Sept. 25, 1972;
8) waste sample tank "B", 1 liter, collected Sept. 25, 1972;
9) waste sample tank (unspecified), 3 liters, collected Aug. 23, 1972 at 1100;
10) waste sample tank "A", 1 liter, acidified, collected July 16, 1973 at 0945;
11) waste sample tank "A", 1 liter, acidified, collected Nov. 29, 1973 at 1500;
12) laundry drain tank, 3 liters, collected Jan. 22, 1972;
13) laundry drain tank, 1 liter, collected Mar. 2, 1972;
14) laundry drain tank, 1 liter, acidified, collected May 16, 1972 at 1305; and
15) laundry drain tank, 1 liter, collected May 16, 1972 at 1305.

Liquid wastes were sampled from only two points in the liquid waste system: 1) the waste sample tanks (the treated effluent from the low and high conductivity waste and chemical waste), and 2) the laundry waste tanks (liquids from the laundry and cask decontamination). These samples are pertinent to the environmental study because radionuclides in these liquid effluents are discharged directly to the coolant-water canal which empties into Barnegat Bay.* The measurement of radionuclides in the wastes, therefore, provides guidance for analyzing samples from the aquatic environment, in which radionuclides are in many cases near or below minimum detectable levels.

The samples obtained on Jan. 18, 1972, April 12, 1972, May 16, 1972, Sept. 15, 1972 and July 16, 1973, were collected while the liquids in the waste sample tank or laundry drain tank were being discharged to Oyster Creek. During these discharges, large water samples were also collected from Oyster Creek. The radionuclide concentrations measured in the latter samples are compared in Section 4.4.4 with concentrations computed from waste sample tank liquid analyses, using the appropriate dilution factors.

4.2.2 *Analysis of waste solutions*. The liquid waste samples were analyzed in a similar manner as the reactor water (Section 2.2.1), except that aliquot volumes were 100 ml or larger since radioactivity levels were much lower. The samples were analyzed spectrometrically with a Ge(Li) gamma-ray detector. The samples were first counted within a day to a week after collection and again several weeks later to identify radionuclides by combining observations of gamma-ray energies and decay rates. The identified radionuclides were quantified by computing disintegration rates from count rates under characteristic photon peaks on the basis of prior counting efficiency calibrations of these detectors. In general, the minimum detectable levels were 1 x 10^{-7} µCi/ml, and only radionuclides with half-lives of 12 hours or more could be detected. The unacidified samples were analyzed radiochemically for ^{3}H, ^{14}C and ^{131}I, and the acidified samples, for ^{32}P, ^{55}Fe, ^{63}Ni, ^{89}Sr and ^{90}Sr.*(5)*

4.3 Results and Discussion

4.3.1 *Radionuclides in waste sample tank*. The radionuclide concentrations measured in liquids from the waste sample tank are listed in Table 4.2. In general, concentrations were low in August 1971 and relatively high in August and September 1972. Although the ^{3}H concentration remained relatively constant during the period of sampling, the concentrations of ^{54}Mn, ^{55}Fe, ^{58}Co, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{131}I, ^{134}Cs and ^{137}Cs were at least 100-fold greater in the later samples, particularly on August 23, 1972. As shown in Figure 2.2, the reactor had been down and started up on August 14, nine days before the sample was collected from the waste sample tank. The higher concentrations measured in this sample, therefore, may be the result of expansion water from the reactor

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Recent operational changes include processing of laundry and cask decontamination waste through the radwaste system.(4)*

Table 4.2 Radionuclide Concentrations in Liquid Waste Sample Tank, pCi/ml

Radionuclide	Aug. 30, 1971	Jan. 18, 1972	Mar. 2, 1972	April 12, 1972	Aug. 23, 1972	Sept. 25, 1972	July 16, 1973	Nov. 29, 1973
^{3}H	1500	1900	3800	4000	1500	1600	NA*	1900 ± 200
^{14}C	< 0.1	0.1	< 0.1	1.9	< 0.1	0.3	NA	NA
^{32}P	1.1	5.0	1.2	3.6	< 0.5	9.7	NA	1.1 ± 0.1
^{51}Cr	10	13	23	46	30	60	36	26 ± 1
^{54}Mn	0.1	3.7	6.1	0.3	330	29	94	39 ± 1
^{55}Fe	0.2	7.5	21	0.9	32	160	NA	2.4 ± 0.1
^{59}Fe	0.1	0.6	1.0	0.2	< 0.1	1.5	16	7.6 ± 0.8
^{58}Co	0.1	1.0	1.5	0.2	90	8.7	5.4	2.4 ± 0.3
^{60}Co	0.5	9.4	18	0.8	2000	157	110	51 ± 1
^{64}Cu	ND*	ND	ND	5.0	ND	ND	ND	ND
^{65}Zn	ND	ND	ND	ND	67	1.8	ND	0.5 ± 0.2
^{76}As	ND	18	1.0	1.5	ND	ND	ND	ND
^{89}Sr	< 0.1	0.5	< 0.1	0.2	30	4.0	0.6	0.10 ± 0.02
^{90}Sr	< 0.01	< 0.01	< 0.01	< 0.05	14	0.4	0.1	< 0.01
^{95}Zr	< 0.1	< 0.1	< 0.1	< 0.1	0.4	0.3	3.8	2.0 ± 0.4
^{95}Nb	< 0.1	0.3	0.2	< 0.1	1.7	< 0.1	6.5	2.6 ± 0.4
^{99}Mo	12	8.5	6.7	20	< 0.5	< 0.5	7.9	10 ± 2
^{103}Ru	< 0.1	0.2	< 0.1	< 0.1	< 0.1	< 0.1	2.1	2.4 ± 0.3
^{105}Rh	< 0.1	11	< 0.1	8.6	< 0.1	< 0.1	< 0.1	< 0.1
^{110m}Ag	ND	ND	ND	ND	0.3	0.7	ND	0.14 ± 0.02
^{124}Sb	< 0.1	0.2	0.6	< 0.1	< 0.1	0.2	2.0	0.7 ± 0.2
^{131}I	1.8	2.0	4.2	4.2	62	19	6.3	16.6 ± 0.6
^{133}I	5.3	2.2	1.7	1.6	NA	NA	NA	NA
^{133}Xe	130	17	NA	1.5	NA	NA	NA	NA
^{135}Xe	100	46	56	30	NA	NA	NA	NA
^{134}Cs	1.0	0.2	0.1	0.1	3200	960	0.4	0.9 ± 0.1
^{137}Cs	0.9	0.4	0.2	0.3	5500	1600	0.7	1.8 ± 0.1
^{140}Ba	< 0.1	1.3	0.4	1.1	1.5	6.0	2.1	0.6 ± 0.1
^{141}Ce	0.5	0.5	2.6	0.9	3.5	1.3	2.2	7.7 ± 0.1
^{144}Ce	< 0.5	< 0.5	< 0.3	0.1	< 0.5	< 0.5	6.3	4 ± 1
^{239}Np	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	< 0.4	11	< 0.4

* NA - not analyzed; ND - not detected.

Notes:

1. The gross alpha activity was < 0.02 pCi/ml for all samples.
2. < values are the 3σ counting error.
3. Uncertainties associated with the radionuclide measurements are not included for the sake of clarity. However, the 2σ counting errors are included in the last column to illustrate probable errors associated with the measurements.

coolant system, but more probably the higher concentrations results from atypical operation of the liquid radwaste system. Leakage of high conductivity water into the waste system required more frequent regeneration of the radwaste demineralizer. This, in addition to the evaporator being inoperative, caused a build-up of water in the radwaste facility preventing regeneration of the condensate demineralizers.*(3)* This high conductivity input to the water system produced an effluent of poor quality from the waste demineralizer, necessitating release of the water to the environment rather than recirculation to the condensate system.*(3)*

A quantitative analysis of the efficiencies for removal of radionuclides by the separate components of the radwaste treatment system was undertaken by AEC participants in the study.*(6)* Consequently, such measurements were not repeated here. Radionuclide concentrations in reactor water (Table 2.1), however, compare with those measured in the waste sample tank as follows:

1) The average tritium concentration in reactor water and in water from the waste sample tank are nearly equal, suggesting that waste water from the various sources (see Figure 4.1) is not significantly diluted by uncontaminated water.
2) The average radionuclide concentrations in liquids from the waste sample tank are lower than those in the reactor water by 1 to 3 orders of magnitude. The ratios of the average radionuclide concentrations measured in reactor water to that measured in liquid from the waste sample tank (C_R/C_W) are:

Radionuclide	C_R/C_W*	d.f. from ref. #6**
^{3}H	1.0	NR†
^{32}P	20	NR
^{51}Cr	150	> 4.6
^{54}Mn	40	> 55
^{59}Fe	590	NR
^{58}Co	300	> 17
^{60}Co	60	43
^{89}Sr	480	1000
^{90}Sr	400	> 55
^{99}Mo	130	NR
^{131}I	820	> 73
^{134}Cs	100	> 78
^{137}Cs	100	> 190
^{140}Ba	770	> 110
^{141}Ce	20	23

* Samples collected in August and September, 1972, were omitted from the calculation since the radwaste treatment system was not operating properly.

**d.f. – decontamination factors measured across the waste collector filter and waste demineralizer combined.

† NR – not reported.

The study of the waste treatment systems at the Oyster Creek station, performed by the AEC in January 1972, yielded the combined decontamination factors in the third column of the above tabulation for the waste collector filter and waste demineralizer.*(6)* Most of these factors are "greater than" because the concentrations measured in the output liquid from the components were below detectable limits. The ratios given in the second column are not actually decontamination factors comparable to values in the third column because all sources of radioactivity to the waste system were not considered and the concentrations in the reactor water do not relate in time to that in the waste sample tank. However, since reactor water leakage is low conductivity waste, the decontamination through the waste collector filter and waste demineralizer will influence the activity ratios given in the second column (see Figure 4.1). In comparison, the ratios are of the same order of magnitude as the decontamination factors given by the AEC study in the third column. This indicates that, except for ^{3}H, considerable decontamination of radioactivity in liquid effluent wastes is achieved when the waste treatment system is operating properly.

To identify the physical or chemical states of radionuclides discharged from the radwaste system, 50-ml aliquots of the sample of September 25 were filtered and then either passed successively through cation- and anion-exchange resins, or equilibrated with carbon tetrachloride and subjected to a silver iodide precipitation. As indicated in Table 4.3, more than one-half of the ^{54}Mn and ^{60}Co and small fractions of the ^{131}I, ^{134}Cs and ^{137}Cs were retained by the filter. Manganese-54 and ^{60}Co are corrosion products and would be associated to a large degree with particulate matter. The soluble ^{54}Mn, ^{60}Co, ^{134}Cs and ^{137}Cs were cationic. The solvent extraction and precipitation of ^{131}I suggest that approximately one-fourth was elemental, one-half was I^- and a few percent were in the form of IO_3^-. In the ion-exchange test, some of the I_2 undoubtedly was adsorbed on both resins, I^- was retained by the anion-exchange resin, and IO_3^- to some extent passed through both resin columns. However, the observed species distribution may not be representative because the radwaste system was not operating properly during sampling.

4.3.2 *Radionuclides in laundry drain tank.* Liquids from the laundry drain tank were sampled three times during the study (see Section 4.2.1). The sources of these liquids are laundry operation and the shipping cask decontamination station. As shown in Figure 4.1, these wastes are discharged directly to the circulating-water coolant canal without any treatment.

The results of the analyses are given in Table 4.4. The major radionuclides present were ^{54}Mn, ^{59}Fe, ^{58}Co, ^{60}Co and ^{137}Cs. Relatively large amounts of ^{3}H and ^{131}I were also in the sample collected on May 16, 1972. The total concentration in the laundry drain tank liquid was about 0.20 uCi/liter. Since the tank volume is 7600

Table 4.3 Chemical States of Radionuclides in Liquid Waste Sample Tank, Sept. 25, 1972

	Percent retained in each separation			
Radionuclide	Membrane filter, 0.45 μ-pore size	Cation-exchange resin, Dowex-50	Anion-exchange resin, Dowex-1	Residue
^{54}Mn	74	26	0	0
^{60}Co	52	48	0	0
^{131}I	9	8	75	8
^{134}Cs	3	97	0	0
^{137}Cs	3	97	0	0
		Solvent extraction, CCl_4	Precipitation, AgI	
^{131}I	12	23	59	6

Notes:

1. Solution was neutral.
2. Order of treatment is from left to right.
3. 50 ml solution passed through resins in columns each 8-cm long, 1.2 cm diameter, at 1 ml/min flow rate.
4. 50 ml solution equilibrated with 50 ml CCl_4, then mixed with 24 mg NaI and excess $AgNO_3$.

liters, the total quantity of radioactivity that might be discharged at any one time is about 1500 μCi.

The average radionuclide concentrations in the liquid from the laundry drain tank are given in Table 4.5. The average annual quantities discharged, based on an annual volume of 9.08 x 10^5 liters (240,000 gal),*(3)* are given in the third column. In the last column are given the percent contribution of radionuclides discharged from the laundry drain tank to that in the total from the laundry drain tank plus the waste sample tank (see Table 4.6). In general, the contribution of radionuclides from the laundry drain tank is minor. Approximately 0.19 Ci of radioactivity is discharged annually from the laundry drain tanks, of which about 50 percent is ^3H.

4.4 Radionuclides in Coolant Canal Water

4.4.1 *Estimated radionuclide concentrations in coolant canal water.* The average quantities of specific radionuclides discharged annually to Oyster Creek are listed in Table 4.6. The concentration of radionuclides in the liquids discharged from the waste sample tank is based on the average measured concentrations before discharge (see Table 4.2) and the average annual volume discharged for the three-year (1971–1973) study period, 1.74 x 10^7 liters.*(3)* Because the liquid waste system was not operating properly prior and during the sampling on August 23, 1972, results from this sample were not averaged into these calculations. The average quantity of radionuclides discharged annually from the laundry drain tank was taken from Table 4.5. The estimated average radionuclide concentrations in Oyster Creek, shown in the last column of Table 4.6, were obtained by dividing the summation of the annual average contributions from the waste sample tanks and the laundry drain tanks by the average annual dilution volume for the three-year period, 1.13 x 10^{12} liters.*(3)* No adjustment in these concentrations was made for recirculation. The total radioactivity discharged annually by the station was calculated to be 54 Ci, which is in agreement with the 1971–1973 annual average liquid discharges reported by the station, 52 ± 18 Ci (see Appendix B.2). These estimated concentrations will be utilized in later sections of this report.

4.4.2 *Sampling and analysis of coolant canal water.* Radionuclide concentrations in the coolant canal during the discharge of liquid wastes were measured to develop and test methods for determining radionuclides at very low concentrations (on the order

Table 4.4 Radionuclide Concentrations in Laundry Drain Tank, pCi/ml

Radionuclide	Jan. 22, 1972	March 2, 1972	May 16, 1972
^{3}H	< 1.5	< 1.5	320 ± 20
^{14}C	0.2 ± 0.1	< 0.1	0.2 ± 0.1
^{32}P	0.3 ± 0.1	NA	0.1 ± 0.1
^{51}Cr	1.6 ± 0.1	0.9 ± 0.1	6.6 ± 0.1
^{54}Mn	41 ± 2	2.0 ± 0.2	11 ± 2
^{55}Fe	5.8 ± 0.1	3.2 ± 0.1	4.9 ± 0.1
^{59}Fe	6.8 ± 0.1	0.5 ± 0.1	4.1 ± 0.1
^{58}Co	9.9 ± 0.1	0.6 ± 0.1	3.4 ± 0.1
^{60}Co	110 ± 5	7.9 ± 0.1	32 ± 5
^{89}Sr	0.20 ± 0.05	< 0.1	0.6 ± 0.1
^{90}Sr	0.020 ± 0.002	< 0.01	0.080 ± 0.002
^{95}Zr	0.6 ± 0.1	< 0.1	2.6 ± 0.1
^{95}Nb	1.6 ± 0.1	0.1 ± 0.1	4.5 ± 0.1
^{103}Ru	0.20 ± 0.05	< 0.1	0.3 ± 0.1
^{124}Sb	1.8 ± 0.1	0.1 ± 0.1	0.5 ± 0.1
^{131}I	ND	< 0.1	1.1 ± 0.1
^{134}Cs	2.7 ± 0.1	0.6 ± 0.1	3.3 ± 0.1
^{137}Cs	5.8 ± 0.1	1.6 ± 0.1	4.3 ± 0.1
^{140}Ba	ND	ND	1.0 ± 0.1
^{141}Ce	0.2 ± 0.1	0.1 ± 0.1	1.0 ± 0.1
^{144}Ce	1.5 ± 0.1	0.2 ± 0.1	1.2 ± 0.1

Notes:

1. ± values are 2σ and < values are 3σ of the counting error.
2. NA - not analyzed; ND - not detected.

Table 4.5 Radionuclides Discharged from the Laundry Drain Tank

Nuclide	Average concentration,[a] pCi/l	Annual average discharge,[b] μCi	Percent of total waste discharged[c]
^{3}H	107,000	97,200	0.23
^{14}C	150	140	1.6
^{32}P	200	180	0.29
^{51}Cr	3,000	2,700	0.51
^{54}Mn	18,000	16,000	3.8
^{55}Fe	4,600	4,200	0.75
^{59}Fe	3,800	3,500	4.8
^{57}Co	100	90	---
^{58}Co	4,600	4,200	7.9
^{60}Co	50,000	45,000	4.9
^{89}Sr	280	250	1.8
^{90}Sr	35	30	2.5
^{95}Zr	1,100	1,000	5.8
^{95}Nb	2,100	1,900	7.2
^{103}Ru	180	160	1.3
^{124}Sb	800	730	7.7
^{131}I	5,600	5,100	3.6
^{134}Cs	2,200	2,000	0.08
^{137}Cs	3,900	3,500	0.09
^{140}Ba	1,000	910	2.9
^{141}Ce	430	390	1.0
^{144}Ce	970	880	3.1

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[a] Average of concentrations given in Table 4.4; < values were averaged as 1/2 < value.

[b] Approximately 9.08×10^{5} liters (240,000 gal.) of laundry waste discharged per year.(3)

[c] The total is the sum of that from the waste sample tank (Section 4.3.1) and the laundry drain tank.

Table 4.6 Estimated Radionuclide Concentrations in Oyster Creek Based on Measured Effluent Concentrations

Radionuclide	Avg. concentration in waste sample tank,(a) pCi/ml	Avg. annual discharge from waste sample tank,(b) μCi	Avg annual discharge from laundry drain tank,(c) μCi	Total annual discharge,(d) Ci	Avg. concentration in Oyster Creek,(e) pCi/l
^{3}H	2450	42.7×10^{6}	9.7×10^{4}	42.8	37.7
^{14}C	0.48	8.4×10^{3}	1.4×10^{2}	0.0085	0.0075
^{32}P	3.6	6.3×10^{4}	1.8×10^{2}	0.063	0.056
^{51}Cr	31	5.4×10^{5}	2.7×10^{3}	0.54	0.48
^{54}Mn	24	4.2×10^{5}	1.6×10^{4}	0.44	0.39
^{55}Fe	32	5.6×10^{5}	4.2×10^{3}	0.56	0.49
^{59}Fe	3.9	6.8×10^{4}	3.5×10^{3}	0.072	0.063
^{58}Co	2.8	4.9×10^{4}	4.2×10^{3}	0.053	0.047
^{60}Co	50	8.7×10^{5}	4.5×10^{4}	0.92	0.81
^{64}Cu	0.7*	1.2×10^{4}	ND**	0.012	0.011
^{65}Zn	0.3	5.2×10^{3}	ND	0.0052	0.0046
^{76}As	2.9	5.1×10^{4}	ND	0.051	0.045
^{89}Sr	0.8	1.4×10^{4}	2.5×10^{2}	0.014	0.012
^{90}Sr	0.07	1.2×10^{3}	30	0.0012	0.0011
^{95}Zr	0.9	1.6×10^{4}	1.0×10^{3}	0.017	0.015
^{95}Nb	1.4	2.4×10^{4}	1.9×10^{3}	0.026	0.023
^{99}Mo	9.3	1.6×10^{5}	ND	0.16	0.14
^{103}Ru	0.7	1.2×10^{4}	1.6×10^{2}	0.012	0.011
^{105}Rh	2.8	4.9×10^{4}	ND	0.049	0.043
^{110m}Ag	0.1	1.7×10^{3}	ND	0.0017	0.0015
^{124}Sb	0.5	8.7×10^{3}	7.3×10^{2}	0.0094	0.0083
^{131}I	7.7	1.3×10^{5}	5.1×10^{3}	0.14	0.12
^{133}I	2.7	4.7×10^{4}	ND	0.047	0.041
^{133}Xe	50	8.7×10^{5}	ND	0.87	0.77
^{135}Xe	58	1.0×10^{6}	ND	1.0	0.88
^{134}Cs	140	2.4×10^{6}	2×10^{3}	2.4	2.1
^{137}Cs	230	4.0×10^{6}	3.5×10^{3}	4.0	3.5
^{140}Ba	1.7	3.0×10^{4}	9.1×10^{2}	0.031	0.027
^{141}Ce	2.2	3.8×10^{4}	3.9×10^{2}	0.038	0.034
^{144}Ce	1.6	2.7×10^{4}	9.8×10^{2}	0.028	0.025
^{239}Np	1.7*	3.0×10^{4}	ND	0.030	0.026

---

* Detected in only one sample: ^{64}Cu (4/12/72) and ^{239}Np (7/16/73).

** ND - Not Detected.

Notes:

a. Average of concentrations given in Table 4.2, omitting the Aug. 23, 1972 sample since the waste treatment system was not functioning. All < values were averaged as 1/2 < value.

b. Average (1971-1973) annual volume of waste discharged:

	1971 - 2.41×10^{7} liters
	1972 - 1.58×10^{7} liters
	1973 - 1.24×10^{7} liters
Average	1.74×10^{7} liters

Average annual discharge = average concentration in waste sample tank (pCi/l) × 1.74×10^{7} liters

c. See Table 4.5.

d. The sum of columns 3 and 4.

e. Average (1971-1973) annual dilution volume:

	1971 - 1.05×10^{12} liters
	1972 - 1.16×10^{12} liters
	1973 - 1.19×10^{12} liters
Average	1.13×10^{12} liters

Average concentration in the discharge canal = total annual discharge (Ci)/1.13×10^{12} liters of 0.1 pCi/liter) in brackish or saline water, and to verify the predicted concentrations in the coolant canal. The high salinity of the coolant canal water precluded the use of the ion-exchange surveillance column used in earlier studies at nuclear power stations, where essentially all cationic and anionic species were concentrated from large volumes of fresh water.*(7,8)*

Methods were developed for the determination of ^{54}Mn, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{131}I, ^{134}Cs, and ^{137}Cs in the coolant canal, where these radionuclides were expected to be in the highest concentrations. Previous studies at another BWR showed that these radionuclides, plus ^{140}Ba, were in coolant canal water.*(7)*

The techniques for concentrating radionuclides from sample volumes of 16 to 400 liters have been reported.*(9)* This description includes the details regarding radionuclide analysis, collection efficiency, and testing of methods.

The concentration system used (see Figure 4.2) collects particulate and certain ionic species. Particulate radionuclides are collected by filtering up to 400 liters of water through a prefilter followed by a 0.45-u membrane filter. The cationic fractions of Mn, Co and Cs are concentrated from the filtrate on the column shown in Figure 4.3. The column consists of a 300-cc section of a chelating ion-exchange resin (Chelex-100) for Mn and Co, followed by a 200-cc section of an inorganic ion exchanger (ammonium hexacyanocobalt ferrate coated on silica gel) for Cs. Early measurements included a 450-cc section of anion resin (Dowex 1 x 8) for concentrating ^{131}I, but the collection efficiency was only 20–60 percent. After concentration of the radionuclides by filtration and ion-exchange, the filters and ion-exchange sections were analyzed with a Ge(Li) detector and multichannel analyzer for gamma-ray-emitting radionuclides.

Strontium-90 and ^{131}I were collected by precipitating $SrCO_3$ and AgI from a 16-liter sample of column effluent. Radiostrontium and radioiodine were determined by reprecipitation as $SrCO_3$ and PdI_2 for determining the gravimetric yield and for beta-particle counting.

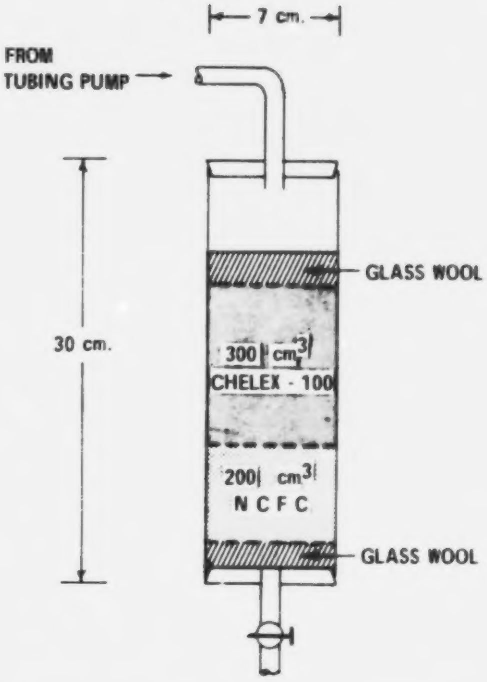

Figure 4.3 Ion exchange column for concentration of Co, Cs, and Mn from seawater.

4.4.3 *Field testing of concentration techniques.* Since few data were available regarding the physicochemical species of the radionuclides in liquid wastes discharged by the station, the concentration techniques were tested in the field to verify collection efficiencies for radionuclides in the same physical and chemical forms present in the coolant canal. Two field tracer experiments were conducted by adding 400 and 1000 ml of liquid waste from the station to approximately 200 liters of coolant canal water in a plastic-lined drum.

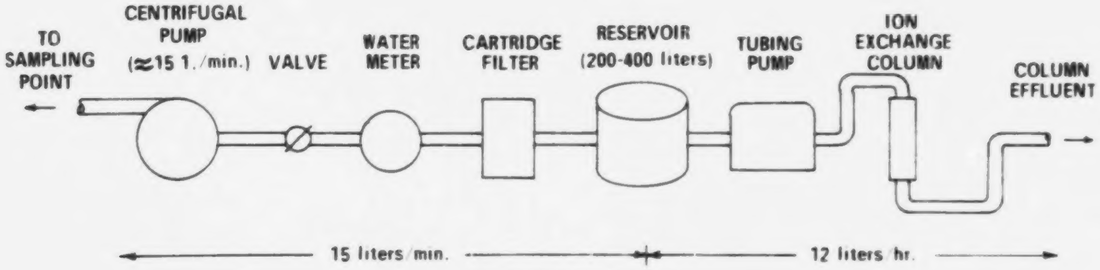

Figure 4.2 Radionuclide concentration system.

The water was circulated for one hour to simulate conditions in the canal and then passed through the concentration system (filters and ion exchange column). Aliquots of the waste solutions were retained to determine the identity and activity of the radionuclides added to the water.

The results of the field tracer experiments are given in Tables 4.7 and 4.8. Recoveries of ^{54}Mn, ^{58}Co, ^{60}Co, ^{134}Cs, and ^{137}Cs were $\geq$ 95 percent. After correction for chemical yield, the recoveries of ^{85}Sr and ^{131}I by coprecipitation were 120 ± 30 and 96 ± 7 percent, respectively (Table 4.8). The first tracer experiment (Table 4.7) afforded a better test of the ion-exchange column since more ^{54}Mn and ^{60}Co remained in the filtrate. The second tracer experiment (Table 4.8) contained a more complex mixture of radionuclides, mostly particles, as indicated by the high recovery on the filter. The tracer experiments demonstrated the validity of these techniques for monitoring the above-cited radionuclides in liquid waste discharged to the seawater environment near the station.

4.4.4 *Coolant canal sampling and results.* On four occasions the radionuclide concentrations in the coolant canal were measured during discharge from the waste sample tank and on one occasion, May 16, 1972, during discharge from the laundry drain tank. Samples of the undiluted wastes were obtained from either the waste sample tank or the laundry drain tank to determine the identity and quantity of discharged radionuclides (see Sections 4.3.1 and 4.3.2). Samples of coolant water from the intake or discharge canals were also collected before or after tank discharge to correct for recirculation of wastes discharged to Barnegat Bay. Intake and discharge coolant water could not be sampled simultaneously because the additional equipment was not available. Water samples from a background location in Great Bay were analyzed to determine the contribution of radionuclides deposited in atmospheric fallout.

The discharge canal sampling location was at the railroad bridge adjacent to the Route 9 bridge, and was approximately 0.8 km downstream from the point of waste discharge. The intake sampling location was at the railroad bridge adjacent to the Route 9 bridge approximately 1.3 km upstream of the waste discharge. Water samples were collected by pumping water from the canal through the filters and collecting the filtrate. Radionuclides in the filtrate were concentrated by passing the filtrate through the ion-exchange system described in Section 4.4.2. The pump intake was located in the center of the canal approximately 2 meters below the surface.

The results of measurements in the coolant canal and Great Bay are given in Tables 4.9 to 4.14. These results showed that the following radionuclides discharged by the station were at concentrations greater than 1 pCi/liter in the coolant canal: ^{51}Cr, ^{54}Mn, ^{58}Co, ^{99}Mo, ^{131}I, ^{134}Cs, and ^{137}Cs. The maximum individual radionuclide concentration in the coolant canal was 6.3 pCi/liter of ^{137}Cs. In addition, ^{60}Co, ^{59}Fe, ^{95}Zr, ^{95}Nb, ^{141}Ce, and ^{144}Ce were detected at concentrations between 0.1 and 1.0 pCi/liter. The unusually high concentration of ^{103}Ru (about 3 pCi/l) on January 25, 1972 was attributed to fresh fallout from the Chinese atmospheric nuclear detonation in January 1972, since ^{103}Ru was not detected in the undiluted waste. Great Bay samples (Table 4.14) showed the presence of several radionuclides attributable to atmospheric fallout at concentrations between 0.1 and 1 pCi/l in the particles collected by filtration on April 12, 1972 and May 16, 1972. These radionuclides were also detected in coolant canal

Table 4.7 Recovery of Radionuclides on Concentration System, September 1972

		Percent recovery					
Radionuclide	Radioactivity added, pCi/liter	Cartridge filter	Membrane filter discs	Chelex-100	NCFC	Dowex-1	Total
^{51}Cr	129 ± 6	102 ± 5	1.8 ± 0.1	<1	1	<1	104 ± 5
^{54}Mn	61 ± 3	69 ± 3	0.10 ± 0.01	29 ± 2	<0.1	<0.1	98 ± 4
^{60}Co	330 ± 15	55 ± 5	0.7 ± 0.1	39 ± 2	<0.1	<0.1	95 ± 4
^{131}I	400 ± 18	1.8 ± 0.1	<0.1	6.7 ± 0.3	<0.1	21 ± 1	30 ± 1
^{134}Cs	1900 ± 100	0.8 ± 0.1	<0.1	8.0 ± 0.4	89 ± 4	<0.1	98 ± 4
^{137}Cs	3400 ± 200	0.8 ± 0.1	<0.1	8.1 ± 0.4	90 ± 4	<0.1	99 ± 4

Notes:

1. 400 ml from waste sample tank B on September 25, 1972 were added to 190 liters of coolant canal water.
2. Coolant canal water: pH 7.5, salinity 24.8 ‰.
3. Total volume passed through the collection system was 175 liters.
4. The ± values are based on 2σ counting errors or a minimum of 5 percent. < values are 3σ counting errors.

Table 4.8 Recovery of Radionuclides on Concentration System, July 1973

Radionuclide	Radioactivity added, pCi/liter	Percent recovered		
		Filter	Ion exchange*	Total
^{51}Cr	303 $\pm$ 15	99 $\pm$ 5	1.2 $\pm$ 0.2	100 $\pm$ 5
^{54}Mn	166 $\pm$ 9	96 $\pm$ 5	0.50 $\pm$ 0.04	96 $\pm$ 5
^{58}Co	11 $\pm$ 0.5	91 $\pm$ 4	6.5 $\pm$ 0.5	98 $\pm$ 4
^{59}Fe	26 $\pm$ 1	95 $\pm$ 4	0.4 $\pm$ 0.2	95 $\pm$ 4
^{60}Co	193 $\pm$ 9	95 $\pm$ 5	2.2 $\pm$ 0.1	97 $\pm$ 5
^{65}Zn	3.2 $\pm$ 0.5	116 $\pm$ 16	7 $\pm$ 2	120 $\pm$ 16
^{89}Sr	13 $\pm$ 1	NA	100 $\pm$ 10**	100 $\pm$ 10
^{90}Sr	0.5 $\pm$ 0.1	NA	120 $\pm$ 30**	120 $\pm$ 30
^{95}Nb	18 $\pm$ 0.5	56 $\pm$ 3	<1	56 $\pm$ 3
^{95}Zr	5.3 $\pm$ 0.5	121 $\pm$ 11	<1	121 $\pm$ 11
^{99}Mo	61 $\pm$ 4	84 $\pm$ 6	<1	84 $\pm$ 6
^{103}Ru	3.7 $\pm$ 0.5	93 $\pm$ 13	<1	93 $\pm$ 13
^{110m}Ag	0.6 $\pm$ 0.3	0.1	67 $\pm$ 16	70 $\pm$ 20
^{124}Sb	3.7 $\pm$ 0.5	100 $\pm$ 14	<1	100 $\pm$ 14
^{131}I	28 $\pm$ 3	57 $\pm$ 6	39 $\pm$ 4**	96 $\pm$ 7
^{134}Cs	2.8 $\pm$ 0.2	25 $\pm$ 12	91 $\pm$ 9	116 $\pm$ 15
^{137}Cs	7.4 $\pm$ 0.5	26 $\pm$ 6	73 $\pm$ 5	99 $\pm$ 8
^{140}Ba	11.1 $\pm$ 1.6	22 $\pm$ 3	<1	22 $\pm$ 3
^{141}Ce	10.1 $\pm$ 0.5	82 $\pm$ 4	4 $\pm$ 1	86 $\pm$ 4
^{144}Ce	22 $\pm$ 3	57 $\pm$ 8	<1	57 $\pm$ 8
^{239}Np	58 $\pm$ 8	35 $\pm$ 5	59 $\pm$ 10	94 $\pm$ 11

* ^{134}Cs and ^{137}Cs were concentrated on the NCFC section; all other cations were retained on the Chelex-100 section.

** ^{89}Sr, ^{90}Sr, ^{131}I determined by precipitation from a 16-liter sample.

Notes:

1. 1000 ml of waste sample tank on July 17, 1973, were added to 208 liters of coolant canal water.
2. Coolant canal water: pH 7.2, salinity 16.4 $^{o}/oo$.
3. Total volume of solution passed through collection system was 190 liters.
4. $\pm$ values are based on a 2σ counting error or a minimum of 5%; $<$ values are 3σ counting errors.
5. NA - Not analyzed

Table 4.9 Radionuclides in Coolant Canal Water on January 18, 1972

Radionuclide	Discharge canal during discharge, pCi/liter Predicted*	 Filters	 Filtrate	Discharge canal before discharge, pCi/liter Filters	Measured/Predicted
^{51}Cr	0.79 ± 0.06	0.9 ± 0.2	NA	<0.5	1.1 ± 0.2
^{54}Mn	0.22 ± 0.02	0.15 ± 0.04	<0.1	<0.5	0.7 ± 0.3
^{60}Co	0.55 ± 0.04	0.4 ± 0.1	0.2 ± 0.1	<0.5	1.1 ± 0.2
^{99}Mo	0.50 ± 0.01	0.40 ± 0.04	NA	NA	0.8 ± 0.1
^{106}Ru	<0.02	2.6 ± 0.4	NA	3.7 ± 0.6	---

*Calculated from waste analysis and dilution factor of 17,000.

Notes

1. Sample volumes: during discharge - 380 liters filtered and 38 liters of filtrate through concentration column; before discharge - 76 liters filtered.
2. Filters: 8-μ and 0.45-μ membrane filter discs in series.
3. NA - not analyzed.

Table 4.10 Radionuclides in Coolant Canal Water on April 12, 1972

Radionuclide	Discharge canal during discharge, pCi/liter Predicted*	 Filters	 Filtrate	Discharge canal before discharge, pCi/liter Filters	 Filtrate	Measured/Predicted
^{51}Cr	2.7 ± 0.1	1.8 ± 0.2	NA	<0.2	NA	0.7 ± 0.1
^{90}Sr	<0.003	NA	0.26 ± 0.02	NA	0.17 ± 0.02	---
^{95}Zr	<0.006	0.36 ± 0.07	NA	0.06 ± 0.04	NA	---
^{95}Nb	<0.006	0.22 ± 0.05	NA	0.05 ± 0.03	NA	---
^{99}Mo	1.2 ± 0.1	1.06 ± 0.08	NA	<0.02	NA	0.9 ± 0.1
^{131}I	0.25 ± 0.02	0.27 ± 0.04	0.12 ± 0.03	<0.02	<0.6	1.2 ± 0.2
^{137}Cs	<0.02	<0.02	0.26 ± 0.05	<0.01	0.34 ± 0.05	---
^{140}Ba	<0.06	0.18 ± 0.06	NA	<0.06	NA	---
^{141}Ce	<0.05	0.30 ± 0.06	NA	0.07 ± 0.03	NA	---
^{144}Ce	<0.01	0.3 ± 0.1	NA	0.06 ± 0.03	NA	---
^{147}Nd	<0.02	0.3 ± 0.1	NA	0.15 ± 0.08	NA	---

*Calculated from waste analysis and dilution factor of 17,000.

Notes:

1. Sample volumes: during discharge - 380 liters filtered and 330 liters of filtrate passed through concentration columns; before discharge - 380 liters filtered and 290 liters passed through concentration column.
2. Filters: 8-μ and 0.45-μ filter discs in series.
3. Water analyses: Oyster Creek pH 7.3, salinity 20.6 ^{0}/oo, suspended solids 2 mg/liter.
4. NA - not analyzed.

Table 4.11 Radionuclides in Coolant Canal Water on May 16, 1972

Radionuclide	Discharge canal during discharge, pCi/liter			Discharge canal before discharge, pCi/liter		Measured/Predicted
	Predicted*	Filters	Filtrate	Filters	Filtrate	
^{51}Cr	0.7 ± 0.1	0.6 ± 0.2	NA	<0.2	NA	0.9 ± 0.4
^{54}Mn	1.14 ± 0.05	0.99 ± 0.09	0.23 ± 0.04	<0.02	<0.07	1.1 ± 0.1
^{59}Fe	0.41 ± 0.02	0.4 ± 0.1	0.11 ± 0.05	<0.07	<0.1	1.2 ± 0.2
^{58}Co	0.34 ± 0.02	0.22 ± 0.04	<0.03	<0.02	<0.1	0.6 ± 0.2
^{60}Co	3.2 ± 0.1	2.1 ± 0.1	0.34 ± 0.04	0.07 ± 0.03	<0.1	0.7 ± 0.1
^{90}Sr	0.010 ± 0.002	NA	0.23 ± 0.04**	NA	0.23 ± 0.04**	---
^{95}Zr	0.26 ± 0.03	<0.05	NA	0.05 ± 0.03	NA	---
^{95}Nb	0.45 ± 0.02	0.19 ± 0.05	NA	0.13 ± 0.03	NA	---
^{131}I	1.11 ± 0.06	0.33 ± 0.08	0.47 ± 0.09	<0.05	0.02 ± 0.01	0.7 ± 0.2
^{134}Cs	0.33 ± 0.02	0.24 ± 0.03	0.11 ± 0.02	<0.02	<0.02	1.1 ± 0.1
^{137}Cs	0.43 ± 0.01	0.42 ± 0.02	0.50 ± 0.03	0.02 ± 0.01	0.40 ± 0.04	1.2 ± 0.1
^{141}Ce	0.10 ± 0.02	0.19 ± 0.05	NA	0.06 ± 0.02	NA	---
^{144}Ce	0.12 ± 0.02	0.4 ± 0.1	NA	0.11 ± 0.03	NA	---

* Calculated from waste analysis and dilution factor of 10,000.

** Determined by analysis of a 16-liter sample of column effluent.

Notes:

1. Sample volumes: during discharge - 200 liters; before discharge - 330 liters.
2. Filters: 8-μ and 0.45-μ membrane filter discs in series.
3. Water analyses: during discharge - pH 7.3; salinity 17.1 ^{0}/oo; suspended solids 32 mg/liter.
   before discharge - pH 7.3; salinity 17.1 ^{0}/oo; suspended solids 26 mg/liter.
4. NA - not analyzed.

Table 4.12 Radionuclides in Coolant Canal Water on September 25–26, 1972

Radionuclide	Discharge canal during discharge on September 25, pCi/liter			Intake canal during discharge on September 26, pCi/liter	
	Predicted*	Filters	Filtrate	Filters	Filtrate
^{54}Mn	0.17 ± 0.01	0.29 ± 0.05	0.04 ± 0.02	0.3 ± 0.1	<0.05
^{60}Co	0.92 ± 0.02	1.1 ± 0.1	0.21 ± 0.02	0.7 ± 0.2	0.24 ± 0.05
^{90}Sr	0.01	NA	0.25 ± 0.02	NA	0.24 ± 0.02**
^{131}I	1.12 ± 0.02	0.07 ± 0.01	0.37 ± 0.04**	<0.05	<0.05
^{134}Cs	5.6 ± 0.1	0.07 ± 0.05	3.3 ± 0.2	<0.05	2.2 ± 0.2
^{137}Cs	9.4 ± 0.1	0.08 ± 0.05	6.3 ± 0.6	<0.1	4.5 ± 0.3

* Calculated from waste analysis and dilution factor of 170,000.

** Determined by analysis of a 16-liter sample of column effluent.

Notes:

1. Sample volumes: discharge canal - 190 liters; intake canal - 150 liters.
2. Filter: 0.45-μ membrane cartridges with prefilter at all locations.

   Water analyses: discharge canal - pH 7.5; salinity 25 ^{0}/oo; suspended solids 15 mg/liter.
   intake canal - pH 7.3; salinity 24 ^{0}/oo; suspended solids 24 mg/liter.

3. NA - not analyzed.

Table 4.13 Radionuclides in Coolant Canal Water on July 17–18, 1973

Radionuclide	Discharge canal during discharge on July 17, pCi/liter Predicted*	 Filters	 Filtrate	Intake canal after discharge on July 18, pCi/liter Filters	 Filtrate**	Measured Predicted
^{51}Cr	0.9 ± 0.1	1.1 ± 0.3	NA	ND	NA	1.2 ± 0.3
^{54}Mn	2.4 ± 0.1	1.9 ± 0.1	0.02 ± 0.01	0.04 ± 0.01	<0.1	0.8 ± 0.1
^{59}Fe	0.42 ± 0.03	0.3 ± 0.1	ND	ND	NA	0.7 ± 0.3
^{58}Co	0.14 ± 0.01	0.12 ± 0.03	ND	ND	<0.1	0.9 ± 0.2
^{60}Co	2.9 ± 0.1	2.0 ± 0.1	0.06 ± 0.01	0.10 ± 0.02	<0.1	0.7 ± 0.1
^{89}Sr	0.015 ± 0.001	NA	0.047	NA	<0.03	---
^{90}Sr	0.003 ± 0.001	NA	0.91 ± 0.01	NA	0.34 ± 0.04	---
^{95}Nb	0.17 ± 0.01	0.18 ± 0.03	NA	ND	NA	1.1 ± 0.2
^{95}Zr	0.10 ± 0.01	0.12 ± 0.04	NA	ND	NA	1.2 ± 0.4
^{103}Ru	0.04 ± 0.02	ND	NA	0.06 ± 0.03	NA	---
^{131}I	0.16 ± 0.01	0.15	0.11	ND	NA	---
^{134}Cs	0.016 ± 0.005	0.01	0.08 ± 0.01	ND	<0.1	---
^{137}Cs	0.02 ± 0.01	0.01	0.46 ± 0.01	0.02 ± 0.01	0.71 ± 0.06	---
^{141}Ce	0.06 ± 0.01	ND	0.06 ± 0.02	0.015	NA	---

* Calculated from waste analysis and dilution factor of 38,000.

** 16 liters were analyzed by sequential analysis.

† Determined by analysis of a 16-liter sample of column effluent or filtrate.

Notes:

1. Sample volumes: discharge canal water - [illegible] liters; intake water - [illegible] liters.
2. Water analyses: discharge canal: pH [illegible], salinity 26.4 ‰, solids 35 mg/liter
   intake canal: pH 7.[illegible], salinity 28.1 ‰, solids 36 mg/liter
3. NA = not analyzed; ND = not detected, generally < 0.01 pCi/liter.

samples on the same dates. This illustrates the necessity of background measurements to differentiate between effluent releases and background contributions. Radiochemical analyses of Great Bay water samples (filtrate only) showed maximum concentrations of 0.2 pCi/liter for ^{90}Sr and 0.5 pCi/liter for ^{137}Cs.

The predicted radionuclide concentrations in the coolant canal, given in Tables 4.9 to 4.13, were calculated from the concentration of radionuclides discharged and the dilution factor in the canal. The dilution factor was assumed to be the ratio of the canal flow rate to waste tank release rate. The waste tank release rates and canal flow rates were obtained from plant personnel. For radionuclides measured with sufficient precision, the ratio of measured to predicted concentrations was calculated after correcting for any contribution from recirculation or fallout. These ratios were not tabulated for the discharge on September 25, 1972 (see Table 4.12), because of atypical station operation. Wastes were being discharged at levels above normal due to problems with the waste treatment system (see Section 4.3.1), and the intake canal concentrations were comparable to those measured in the discharge canal during this waste discharge. Measurements in the discharge canal, corrected for recirculation, were approximately 4 to 5 times lower than expected for this sample. Factors that could explain lower than predicted concentrations include:

1. the waste tank sample was not representative of the waste being discharge during sampling;
2. wastes were not discharged during the entire sampling period;
3. the canal flow rate was higher than the station value;
4. sedimentation or settling of suspended material.

With the exception of the discharge on September 25, 1972, the measured to predicted values ranged from 0.6 to 1.2 for the radionuclides shown to be quantitatively retained on the filters and ion-exchange column. The measured to predicted ratio was also near unity for ^{51}Cr and ^{59}Fe. Considering the uncertainties involved in this type of measurement, the relatively good agreement verified the dilution factors calculated from waste

Table 4.14 Radionuclides in Background Seawater (Great Bay), pCi/liter

Radionuclide	April 12, 1972 Filters	April 12, 1972 Filtrate	May 16, 1972 Filters	September 27, 1972 Filters	September 27, 1972 Filtrate
^{51}Cr	< 0.2	NA	< 0.06		
^{54}Mn			< 0.05	< 0.03	< 0.1
^{59}Fe			< 0.02		
^{58}Co			< 0.01		
^{60}Co			< 0.05	< 0.03	< 0.1
^{90}Sr	NA	0.24 ± 0.02		NA	0.24 ± 0.02
^{95}Zr			0.10 ± 0.02		
^{95}Nb	0.9 ± 0.1	NA	0.03 ± 0.01		
^{99}Mo					
^{131}I	0.1 ± 0.05	NA		< 0.02	NA
^{134}Cs			< 0.01	< 0.01	< 0.1
^{137}Cs	< 0.02	< 0.5	< 0.01	< 0.01	0.5 ± 0.2
^{140}Ba	0.2 ± 0.1	NA	< 0.02		
^{141}Ce	1.1 ± 0.1	NA	< 0.06		
^{144}Ce	0.63 ± 0.07	NA	< 0.06		
^{147}Nd	0.86 ± 0.09	NA			

Notes:

1. Sample volumes: April 12, 1972 - 300 liters filtered, 16 liters of filtrate analyzed for ^{90}Sr and ^{137}Cs.
   May 16, 1972 - 210 liters filtered, filtrate was not analyzed.
   September 27, 1972 - 210 liters, 16 liter samples analyzed for ^{90}Sr, ^{54}Mn, ^{60}Co, ^{137}Cs, and ^{134}Cs.
2. NA - not analyzed.

effluent release rates and canal flow rates. Some of these uncertainties include:

1. dilution factors based on nominal values of waste release and canal flow rates;
2. homogeneous mixing of waste and canal water is assumed;
3. radionuclides may deposit from canal water prior to sampling or may be resuspended from canal sediment;
4. recirculation effects were not measured simultaneously with discharge canal sampling;
5. measurements of radionuclides in liquid wastes after dilution with seawater have considerable associated uncertainties because of the low concentrations.

The high particulate concentration of some radionuclides in the coolant canal is evident from the data presented in Table 4.15. From 60 to 100 percent of the ^{51}Cr, ^{54}Mn, and ^{60}Co were associated with particles collected by filtration. The low retention of ^{134}Cs and ^{137}Cs by filtration was similar to that observed in liquid from the waste sample tank (see Table 4.3). On May 16, 1972, however, 41 and 46 percent, respectively, were associated with particles during a discharge from the laundry drain tank, which may have had a higher fraction of particulate radiocesium than the liquids from the waste sample tank. In general, the fractions of ^{54}Mn and ^{60}Co associated with particles in the circulating coolant water are significantly higher than that observed in liquids from the waste sample tank (see Table 4.3). This would indicate the formation of or adsorption on particulate matter in the coolant canal after release. Other radionuclides retained efficiently by filtration were ^{95}Nb, ^{95}Zr, ^{140}Ba, ^{141}Ce, and ^{144}Ce.

4.4.5 *Summary of coolant canal measurements.* The coolant canal measurements and tracer studies provided an excellent opportunity to develop and verify techniques for monitoring selected radionuclides discharged by the station to a seawater environment. It was apparent from the variable distribution of

Table 4.15 Particulate Radionuclides in Coolant Canal

Radionuclide	Percent of measured concentration retained on filters			
	Jan. 18, 1972	May 16, 1972	Sept. 25, 1972	July 17, 1973
^{51}Cr*	---	86 ± 30	---	100 ± 20
^{54}Mn	>60	81 ± 8	88 ± 20	99 ± 5
^{60}Co	70 ± 20	88 ± 5	84 ± 12	97 ± 5
^{134}Cs	---	41 ± 4	4 ± 2	< 15
^{137}Cs	---	46 ± 5	3 ± 1	< 5

*Filtrate was not analyzed for ^{51}Cr; the predicted concentration was used instead of the total measured concentration.

radionuclides between particulate and dissolved species that monitoring techniques in the aqueous environment of nuclear power stations should be tested under actual conditions to ensure that all physico-chemical species are collected. The concentrations of major radionuclides in the coolant canal were between 0.1 and 10 pCi/l during waste discharge and generally consistent with predicted values. The coolant canal studies showed that monitoring waste discharges after dilution was difficult because of low concentrations and recirculation effects. The advantages and validity of predicting radionuclide concentrations discharged to Barnegat Bay by analysis of the liquid waste before dilution and application of the calculated dilution factor were shown.

The observation that several radionuclides in the coolant canal were mostly particulate suggests that realistic predictions of radionuclide levels in aquatic organisms based on effluent concentrations would require additional information regarding the physico-chemical species of these radionuclides in seawater.

4.5 References

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6. Pelletier, C. A., "Results of Independent Measurements of Radioactivity in Process Systems and Effluents at Boiling Water Reactors," USAEC Rept., unpublished (May 1973).

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5. RADIONUCLIDES IN THE AQUATIC ENVIRONMENT

5.1 Introduction

5.1.1 *Oyster Creek and Barnegat Bay hydrology (1–4)* Condenser cooling water is taken from Barnegat Bay through a canal extending from the south branch of Forked River and discharged through another canal to Oyster Creek which empties into the bay about 1.8 km south of Forked River (see Figure 5.1). Both Forked River and Oyster Creek are small streams. The average natural discharge of the south branch of Forked River was estimated to be less than 0.14 m^3/s, while for Oyster Creek the mean daily flow during 1966–1969 was 0.71 m^3/s with a maximum of 3.5 m^3/s and a minimum of 0.34 m^3/s. *(3)* The station utilizes about 1.2×10^{11} liters/month which creates a flow in Oyster Creek during operation of about 45 m^3/s. *(5)* As the volume of Barnegat Bay is approximately 2.4×10^{11} liters, *(3)* one-half bay volume of water is used by the station each month. Hence, the fresh water flow in these streams is insignificant relative to this large demand which has resulted in a reversal of the flow in Forked River producing a brackish water environment up Forked River from the bay through the south branch and in Oyster Creek. Also, when conditions in the bay are such that the discharge from Oyster Creek is forced northward along the west shore, recirculation of station effluents occurs.

Barnegat Bay (see Figure 5.2) is about 50 km long with a maximum width of 6.4 km. The bay is shallow, having an average depth of 1.5 m and a maximum depth of 6 m. It is isolated from the ocean on the east by two narrow barrier beaches, Island Beach and Long Beach, separated by Barnegat Inlet which lies approximately midway on the bay and 7 km SE from Oyster Creek. Barnegat Inlet provides the main access to the ocean, as the bay is essentially closed to the north and contains only a small channel into Beach Haven Inlet at the southern end. The maximum tidal range of the bay is 1 m, while at the mouth of Oyster Creek it is only about 0.15 m.

The mixing of radionuclides discharged from Oyster Creek to the bay is complicated and difficult to predict. The movement of water in the bay and through Barnegat Inlet to the ocean is under the influences of tidal forces, local wind stresses, the hydraulic head produced by runoff of rainfall, and density differences due to salinity and temperature gradients. Due to the shallowness of the bay, wind can be predominant in mixing and moving water in the bay. The circulation of water through Forked River and Oyster Creek will also affect the movement of bay water in the vicinity of Oyster Creek, since this amounts to an approximately one-half bay volume per month (see above).

A month-long study of bay water mixing and its transfer to the ocean was performed by Carpenter during August 1963. *(1)* Rhodamine B dye was continuously introduced into the water in the mouth of Oyster Creek during a period when water-borne materials discharged to the bay would be transferred to the ocean at a minimum rate. Runoff into the bay was minimal and the winds were low to moderate. Hence, concentrations near the mouth of Oyster Creek were expected to be near maximum during the study month. The observations can be summarized as follows:

(1) The average (minimum) exchange rate of Barnegat Bay with the ocean is about 14 percent a day and the half-life for the exchange process is about 5 days.

(2) All fresh water is introduced to the bay along the west shore, which produces a density gradient across the bay from west to east. The resulting pressure gradient in combination with the Coriolis force produces a current to the south. This movement is in addition to the movement produced by the hydraulic head associated with run-off accumulation in the enclosed basin to the north of the inlet.

(3) The predominant wind from the south produced a flow to the north during the study. This caused a pressure gradient due to accumulation of water in the enclosed northern portion of the bay, as the expected circulation to the south below the surface is prevented by the shallowness of the bay. The result is a reduced displacement of the water. It is expected, however, that some circulation to the south occurs near the shore where the wind speed is less. A wind from the north

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would force a flow to the south, but a smaller pressure gradient would develop as flow from the bay would occur through Beach Haven Inlet at the southern end of Barnegat Bay. The data show that winds can have a greater influence than tidal action on the movement of water in the bay.

(4) The bay end of the channel to Barnegat Inlet lies only 1.6 km to the south of the mouth of Oyster Creek. Materials discharged from Oyster Creek that drift south are rapidly flushed along the channel into the ocean during ebb tide. Hence, material that is in this area at the beginning of ebb tide is discharged directly into the ocean. Relatively constant vertical salinity profiles in the central portion of the bay indicate the strong influence of tidal action in this region.

(5) Concentration profiles for a constant discharge derived from the data are not particularly applicable to actual station discharges. That is, after termination of a periodic batch discharge, the concentration at some point in the bay, depending on the conditions discussed above, will exceed that in Oyster Creek.

This complex hydrology of the bay and the batchwise discharge of wastes by the station make it extremely difficult to predict quantitatively the concentration of radionuclides relative to time of discharge by the station and location in the bay.

5.1.2 *Studies near Oyster Creek.* The measurements described in Section 4.4 showed that radionuclides from the Oyster Creek Nuclear Power Station were in the circulating coolant water discharge canal (Oyster Creek) and possibly were in measureable concentrations in Barnegat Bay. Sampling was mostly confined to Oyster Creek and Barnegat Bay between Cedar Creek and Waretown. Some samples were collected from other areas of the bay to determine overall radionuclide distribution. Samples of water, macro-algae, aquatic plants, fish, clams, crabs and sediment were collected. These studies are described in detail in Sections 5.2 to 5.7.

5.1.3 *Aquatic surveillance studies by station operator.* Radioactivity in the aquatic environment is monitored by the station operator and reported quarterly *(5)*. Samples of surface water, silt and clams are collected routinely and analyzed for gamma-ray emitters, ^{90}Sr and gross alpha and beta radioactivity. Surface water is sampled at five sites: one in Forked River, one in Oyster Creek, and three in the bay (near the mouth of Oyster Creek, 3.2 km NE of Forked River and about 3 km east of Waretown). Silt samples are collected from the same five sites as surface water, while clams are collected from the three bay sites. Average concentrations in samples are reported each quarter for the combined sites. The station operator's aquatic analyses summarized semi-annually for January 1970 to November 1973 are given in Appendix E.1. The results of the four-year surveillance program show no increase of radioactivity in these samples with time. Except in the few cases of ^{65}Zn in clam meat, the results are similar to preoperational data. The ^{65}Zn concentrations were slightly above the minimum detectable level of 0.09 pCi/gm.

5.1.4 *Aquatic surveillance studies by the State.* The New Jersey State Department of Environmental Protection, Bureau of Radiation Protection (BRP), has conducted a thorough radiological surveillance program of the aquatic environment in the vicinity of the nuclear power station since 1970 *(6, 7)*. This study included a greater variety of aquatic samples than that of the operator's program discussed above. Samples analyzed were surface water, silt, benthic macro-algae, aquatic plants, fish, clams and crabs. The principal station-produced radionuclides observed in these samples were ^{54}Mn and ^{60}Co. The results of the state's 1971 and 1972 surveillance program are discussed below *(6, 7)*.

Grab samples of surface water were obtained during 1971 and 1972 from Oyster Creek, Forked River, Barnegat Bay and Great Bay. Station-produced radionuclides were detected in concentrations above the minimum detectable level only in Oyster Creek and Forked River. However, results based on grab samples are not particularly informative because they are dependent upon sampling time relative to the time of station discharge as well as conditions in the bay (discussed in Section 5.1.1). The BRP sampled water continuously in Oyster Creek at Sands Point Marina from April through December 1972 and in the South Branch of Forked River at the station condenser inlet from January to April 1973 *(7)*. The average concentrations are given in Appendix E.2. Although all concentrations are low, they reflect higher levels of reactor-produced radionuclides in Oyster Creek than in Forked River.

Average annual radionuclide concentrations for sediment samples collected in 1971 and 1972 from Oyster Creek, Forked River and Barnegat Bay are also given in Appendix E.2. The 1972 concentrations of ^{54}Mn and ^{60}Co in sediments were significantly less than in 1971. Zinc-65 was not detected ($<$ 0.2 pCi/g) and only possible traces of ^{58}Co ($<$ 0.15 pCi/g) and ^{137}Cs ($<$ 0.15 pCi/g) were present. These results indicate that effluents from the station are deposited in Oyster Creek, Forked River and along the west shore of Barnegat Bay, possibly as far north as Cedar Creek.

Radionuclide concentrations were measured in benthic macro-algae and marine grasses collected from Barnegat Bay and several other sites in the vicinity. The most commonly sampled species were *C. fragile, U. lactuca, G. verrucosa* and the grass, *Z. marina*. The average radionuclide concentrations are listed in Appendix E.2 for samples collected in 1971 and 1972 from sites in the bay near the mouth of Oyster Creek, near the mouth of Cedar Creek and east of Waretown. Radionuclides were concentrated from the water in all species. The greatest concentrations were measured in *G. verrucosa* and the least in *C. fragile*. The average concentrations in all species were significantly higher in 1971. The fallout radionuclide, ^{103}Ru, was observed only in 1972. The two standard deviation uncertainties for the ^{58}Co values in 1971 are included to indicate the small differences, in some cases, between the average concentration and the minimum detectable level. Stems and roots of four samples of *Z. marina* were analyzed separately and the roots were found to contain more than twice the ^{54}Mn and ^{60}Co (root/stem = 2.1 ± 0.3).

Radionuclide concentrations were measured in whole fish collected from Barnegat Bay during 1971 and 1972. Concentrations were generally below minimum detectable levels. Of 13 samples collected in 1972, trace amounts of ^{60}Co were observed in 5 samples, ^{137}Cs in 6 samples, ^{134}Cs in one sample and ^{90}Sr in 8 samples. Since the whole fish was analyzed, it is not known with which tissues these radionuclides were associated.

The average radionuclide concentrations and the concentration range observed in shellfish *(Mercenaria mercenaria)* meat collected from Barnegat Bay near Waretown and near the mouths of Oyster and Cedar Creeks are listed in Appendix E.2. The principal radionuclides discharged by the station and detected in the clam meat are ^{54}Mn, ^{58}Co and ^{60}Co. As observed in the sediment and algae samples, concentrations in clams collected during 1972 were less than in 1971.

No significant radionuclide concentrations were observed in crab meat collected in 1972. Two samples collected from Oyster Creek in 1971 contained small quantities of ^{58}Co, ^{60}Co and ^{65}Zn.

The results described briefly above, abstracted from BRP reports,*(6, 7)* will be utilized in later discussions.

5.1.5 *Other aquatic studies.* A number of non-radiological environmental studies have been conducted in Barnegat Bay near Oyster Creek. Benthic flora and fauna of Barnegat Bay have been studied since 1965 by Rutgers University to assess the species population before and after the onset of warm water discharges by the station.*(8)* A finfish study of Barnegat Bay was also performed by the Department of Environmental Sciences at Rutgers University.*(9, 10)* A census consisting of more than 60 species of fish was obtained. The results of these studies will be utilized in the discussions appearing later in this report.

Some studies are in progress from which data are not yet available. These include the continuation of the studies by Rutgers, and a benthic survey of the New Jersey coastal waters by the Sandy Hook Laboratory, U.S. Department of Commerce, NOAA, which also considers the effects of thermal addition on benthic algae and organisms. New Jersey's Department of Environmental Protection, Bureau of Fisheries, has recently completed a study of bay finfish and related physical and chemical parameters, but the report has not been published.

5.2 Surface Water Concentration of Radionuclides and Stable Elements

5.2.1 *Sampling and analysis.* Eight-liter water samples were collected from Oyster Creek, Forked River, Barnegat Bay and Great Bay during each field trip at the sites from which flora and fauna were obtained. Sampling was repeated four times during a 12-month period at three sites in Barnegat Bay, near Waretown and near the mouths of Oyster and Cedar Creeks, and from Great Bay, the control sampling site indicated by an X in Figure 5.2. The dates on which the samples were collected and the site locations are listed in Table 5.1 and shown in Figures 5.1 and 5.2. The water temperatures and salinities were measured at the time of sampling.* The unacidified water samples were returned to the laboratory in polyethylene bottles for analysis.

Two-liter aliquots of the water samples were analyzed for ^{90}Sr and ^{137}Cs by the sequential procedure described in Section 4.4.2. Samples collected during October 18–21, 1971, were also analyzed for ^{54}Mn and ^{60}Co using the same procedure. The stable elements, except potassium, were determined by atomic

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*Water temperature determinations were made using a Model 43-TD Telethermometer of the Yellow Springs Instrument Company. Salinities were determined with a Model 10423 Goldberg Refractometer specifically designed by American Optical Instrument Company for direct reading measurements.

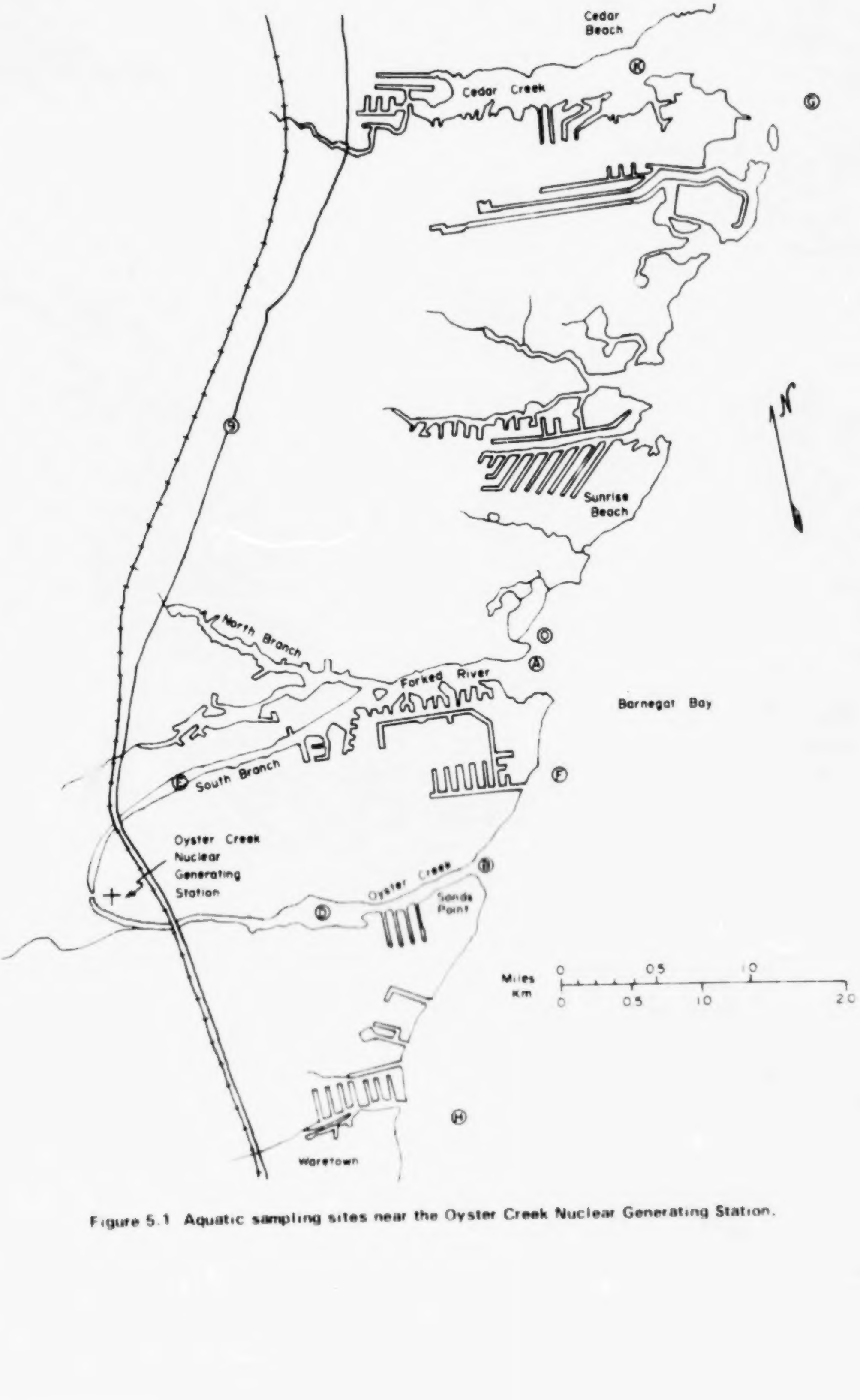
Cedar Beach
Cedar Creek
Ⓚ
Ⓖ
N
⑨
Sunrise Beach
Ⓒ
Ⓐ
North Branch
Forked River
Barnegat Bay
Ⓔ
South Branch
Ⓕ
Oyster Creek Nuclear Generating Station
Oyster Creek
Ⓑ
Sands Point
Ⓓ
Miles
Km
0
0.5
1.0
0
0.5
1.0
2.0
Ⓗ
Waretown

Figure 5.1 Aquatic sampling sites near the Oyster Creek Nuclear Generating Station.

Table 5.1 Concentration of Stable Elements in Surface Water

Date Collected	Location*	Water temperature, °C	Salinity (ppt)	Ca (mg/1)	Sr (mg/1)	K (mg/1)
Oct. 18, 1971	D	NM**	16	190	4.2	NM
Oct. 19, 1971	F	NM	22	290	5.4	NM
Oct. 21, 1971	E	NM	22	NM	NM	NM
Oct. 21, 1971	I	NM	24	281	5.7	NM
Oct. 21, 1971	C	16	20	248	4.9	NM
Oct. 21, 1971	G	17	21	257	5.3	NM
April 17, 1972	GB-X	13	29	333	6.7	NM
April 18, 1972	H	11	25	281	5.4	NM
April 18, 1972	B	15	24	NM	NM	NM
April 19, 1972	G	13	22	219	5.1	NM
July 10, 1972	GB-X	24	28	295	5.6	206
July 11, 1972	H	NM	28	262	5.2	205
July 12, 1972	B	33	23	219	4.6	210
July 12, 1972	G	24	24	286	5.3	190
Oct. 31, 1972	GB-X	11	23	NM	NM	NM
Oct. 31, 1972	L	10	28	NM	NM	NM
Nov. 1, 1972	H	11	22	276	5.4	NM
Nov. 1, 1972	B	13	22	267	5.1	NM
Nov. 1, 1972	G	11	22	276	4.9	NM
Nov. 2, 1972	N	10	16	228	4.5	NM
Nov. 2, 1972	M	11	17	276	5.2	NM

* See Figures 5.1 and 5.2 for sampling locations; GB-X indicates site X in Great Bay.

** NM - not measured.

Note: Stable elements below the minimum detectable level were: Fe (<0.07 mg/1), Mn (<0.1 mg/1) and Co (<0.2 mg/1).

absorption spectrophotometry. Potassium concentrations were based on ^{40}K radioactivity, assuming 848 pCi ^{40}K/gK.

In addition to the 8-liter water samples described above, larger volumes of water were collected on May 15–16, 1972, and September 28, 1972. In the earlier case, 105– to 210-liter samples from 5 sites in Barnegat Bay and one site in Great Bay were filtered through 8– and 0.45-micron membrane filters in series, and 20 liters of the filtrate were retained for sequential analysis of ^{54}Mn, ^{60}Co, ^{90}Sr and ^{137}Cs. On the second occasion, 150– to 380-liter samples from 5 sites in Barnegat Bay were passed through 0.45-micron cartridge filters (see Section 4.4.3) and the filtrate was discarded. The membrane and cartridge filters were analyzed by gamma-ray spectrometry with a 54-cm^3 Ge(Li) detector. Since the filtrates were not analyzed in the latter sampling, only the insoluble or particulate radionuclides were measured.

5.2.2 *Stable elements in surface water.* The concentration of stable strontium, calcium and potassium measured in water samples from Oyster

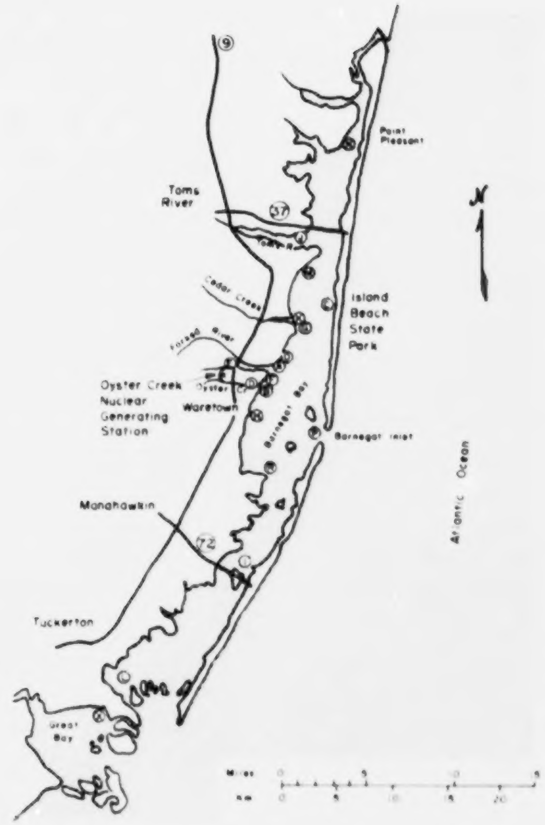

Figure 5.2 Aquatic sampling sites in the area of the Oyster Creek Nuclear Generating Station.

Creek, Forked River, Barnegat Bay and Great Bay are listed in Table 5.1. Concentrations of iron, manganese and cobalt were below minimum detectable levels in all samples. Also included in the table are the water temperatures and salinities* at the time of collection. Being an estuarine environment, the salinities and stable element concentrations vary somewhat, but not greatly within Barnegat Bay. The lowest salinities were measured in Oyster Creek (D) and at the northern end of Barnegat Bay (N), where the influence of fresh water is greatest (see Section 5.1.1). Salinities were relatively high in Great Bay, which is more open to the ocean than Barnegat Bay. The average salinity of all water samples is 23 ± 4 ‰. Since the mean salinity of Atlantic Ocean water is 34.90 ‰ *(4)* the water in the vicinity of Oyster Creek consists of about 66 ± 10 percent ocean water and 34 ± 6 percent fresh water.

In the first line of Table 5.2 are presented the mean concentrations in mg/liter of stable calcium, strontium and potassium, with the standard deviations of the individual measurements. The Sr/Ca ratios of the water samples from the bay varied between 17.8 and 23.3 mg Sr/g Ca, with a mean and standard deviation of 19.9 ± 1.3 mg Sr/g Ca. Concentrations of iron, manganese and cobalt were below the minimum detectable levels indicated and could not be measured. Since salinity is a measure of dissolved salts, principally Na, Mg, Ca and K, it indicates the relative amounts of fresh water and sea water. In principle, it is possible to estimate the concentration of stable elements in the bay water from salinity measurements and concentrations normally observed in fresh and pelagic ocean water. Given in Table 5.2 are the concentrations reported to be in fresh and pelagic Atlantic Ocean water. An approximate concentration is obtained by summing the products of the fresh and ocean water concentrations multiplied by the measured mean salinity fractions given above, 0.34 ± 0.06 and 0.66 ± 0.10, respectively.[†] The estimated concentrations are given in the last line of Table 5.2. The calculated concentrations for calcium, strontium and potassium agree with the measured mean concentrations. This might be expected since the concentration of these elements are relatively uniform in pelagic ocean waters and relatively small in fresh water. The concentrations calculated for iron, manganese and cobalt, however, depend on their normally greater concentrations in fresh water, which vary greatly between geographical locations. For these elements a concentration range has been calculated which spans one or more magnitudes.

These values indicate that measurement of Mn, Fe and Co requires an increase in analytical sensitivity of at least two orders of magnitude. This can be done by altering the analytical technique or incorporating a concentration process into the procedure. Knowledge of these concentrations is useful, as their radioactive isotopes are discharged by the station and their presence influences the uptake of the radioactive isotope by marine organisms.

5.2.3 *Radionuclides in surface water.* The results of the radiochemical analyses of the 8-liter grab samples collected during October 1971 and three times during 1972 are listed in Table 5.3. Since the volumes available for each analysis were only 2 to 4 liters and the radionuclide concentrations were quite low, the results

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*Salinities are given in units of parts per thousand (ppt)

[†] An example of this calculation for Ca is 15 mg/l x 0.34 + 400 mg/l x 0.66 = 269 mg/liter

Table 5.2 Average Measured and Estimated Stable Elements in Water, mg/l

Source	Ca		Sr		K	
	Fresh	Sea	Fresh	Sea	Fresh	Sea
This study	260 ± 32		5.3 ± [illegible]		280 ± 20	
Ref. 11	15	400	0.1	8	[illegible]	380
Ref. 12	—	410	—	7.7		
Ref. 13	11-75	400	0.02-0.19	8.1		
Ref. 14	15	410	0.07	8	2.3	380
Ref. 15	—	400	—	8.1	—	390
Est. conc.*	270 ± 30		5.3 ± 0.5		245 ± 30	

Source	Cs		Mn		Co	
	Fresh	Sea	Fresh	Sea	Fresh	Sea
This study	0.07		0.11		0.2	
Ref. 11	0.1	0.001	0.01	0.002	0.0002	0.001
Ref. 12	—	—		0.001		0.00013
Ref. 13	0.005–0.2	0.0005	[illegible]	0.002	0.004–0.007	0.0005
Ref. 14	—	0.0005	0.007	0.002	0.001	0.0004
Ref. 15	—	0.0005–0.002		0.002–0.003	—	0.0005
Est. conc.*	0.012–0.048		0.005–0.017		0.0001–0.0027	

*Computed estimated concentration = 0.34 x conc. in fresh water + 0.66 x conc. in sea water.

reflect considerable uncertainty in the measurements. The ^{137}Cs concentration in Barnegat Bay ranged from 0.2 to 1.3 pCi/liter. The ^{137}Cs concentrations in background samples from Great Bay were 0.4 ± 0.1 and 0.3 ± 0.1 pCi/liter, similar to that observed in Chesapeake Bay water (about 0.3 pCi/liter).*(16)* Only three samples from Barnegat Bay had ^{137}Cs concentrations at or in excess of 1 pCi/liter. After correcting the measured concentrations for the background ^{137}Cs from fallout, the ^{137}Cs concentrations of all Barnegat Bay samples were less than 1 pCi/liter, and the average concentration in the bay resulting from station discharges was about 0.3 pCi/liter.

The ^{90}Sr concentrations in the Barnegat Bay water samples varied from < 0.1 to 2.6 pCi/liter. The ^{90}Sr concentrations of two background samples from Great Bay were 0.50 ± 0.06 and 0.36 ± 0.04 pCi/liter, with an average specific activity of 0.070 ± 0.008 pCi ^{90}Sr/mg Sr. The only samples having ^{90}Sr concentrations significantly greater than that of the background samples were those collected during the period of October 18–21, 1971. The average specific activity of these samples was 0.37 ± 0.08 pCi ^{90}Sr/mg Sr, while in samples collected during 1972 the average specific activity was 0.07 ± 0.04, similar to that in samples from Great Bay. After correcting the measured values for the background contribution from fallout, the ^{90}Sr concentrations in the October 1971 samples varied from 1.3 to 2.2 pCi/liter. These samples were collected during the month when the station reported discharging the highest ^{90}Sr levels during 1971 and 1972. The average ^{90}Sr concentration in Oyster Creek was 1.57 pCi/liter during October 1971 compared to annual averages of 0.34 and 0.21 pCi/liter of ^{89}Sr + ^{90}Sr in 1971 and 1972, respectively (see Appendix B.4). In view of the relatively high level of ^{90}Sr discharged in October 1971, the ^{90}Sr concentrations observed in Barnegat Bay water samples during this period are reasonable and attributable to station discharges.

Manganese-54 concentrations in the Barnegat Bay water samples collected during October 18–21, 1971 were less than 3 pCi/liter, and, with the exception of two locations, ^{60}Co concentrations were less than 2 pCi/liter. The ^{60}Co concentrations of samples collected near the mouth of Cedar Creek (G) and off Island

Table 5.3 Concentration of ^{90}Sr and ^{137}Cs in Barnegat and Great Bay Water Samples

Date Collected	Location**	^{137}Cs, pCi/l	^{90}Sr, pCi/l
Oct. 18, 1971	D	0.8 ± 0.2	1.7 ± 0.4
Oct. 19, 1971	F	1.0 ± 0.2	1.9 ± 0.4
Oct. 21, 1971	L	0.9 ± 0.2	1.5 ± 0.3
Oct. 21, 1971	I	0.7 ± 0.2	1.5 ± 0.3
Oct. 21, 1971	C	0.5 ± 0.2	1.8 ± 0.3
Oct. 21, 1971	G	0.5 ± 0.2	2.6 ± 0.4
April 17, 1972	GB-X	0.3 ± 0.1	0.50 ± 0.06
April 17, 1972	H	0.1 ± 0.1	NA*
April 18, 1972	B	1.3 ± 0.3	0.58 ± 0.05
April 19, 1972	G	0.2 ± 0.1	0.25 ± 0.05
July 10, 1972	GB-X	0.4 ± 0.1	0.36 ± 0.04
July 11, 1972	H	0.4 ± 0.1	0.24 ± 0.05
July 12, 1972	B	0.8 ± 0.2	0.19 ± 0.04
July 12, 1972	G	1.0 ± 0.2	0.26 ± 0.04
Oct. 31, 1972	GB-X	NA	NA
Oct. 31, 1972	L	NA	NA
Nov. 1, 1972	H	0.8 ± 0.2	0.9 ± 0.1
Nov. 1, 1972	B	0.8 ± 0.2	0.5 ± 0.1
Nov. 1, 1972	G	0.6 ± 0.2	0.4 ± 0.1
Nov. 2, 1972	N	0.4 ± 0.1	<0.1
Nov. 2, 1972	M	0.6 ± 0.1	0.2 ± 0.1

* In all samples the ^{54}Mn and ^{60}Co concentrations were <3 pCi/l and <2 pCi/l, respectively, except for those collected Oct. 21, 1971, at locations C and G in which the ^{60}Co concentrations were 3 ± 2 and 7 ± 2 pCi/l, respectively.

** Locations refer to Figure 5.1; GB-X indicates site X in Great Bay.

NA = not analyzed; ± values are 2σ and < values are 3σ of the count rate.

Beach (C) were 7 ± 2 and 3 ± 2 pCi/liter, respectively. These concentrations appear high compared to the average calculated ^{60}Co concentration of 1.05 pCi/liter in Oyster Creek during October 1971 (see Appendix B.4). It is possible that these samples were collected after discharge of wastes in Oyster Creek that produced ^{60}Co concentrations substantially greater than the monthly average. Samples collected during 1972 were not analyzed radiochemically for ^{54}Mn or ^{60}Co.

The large volume water samples collected during the period May 15-16, 1972, show no ^{54}Mn, ^{60}Co, ^{90}Sr or ^{137}Cs attributable to station operation (see Table 5.4). During this period, only laundry wastes were being discharged. Manganese-54 and ^{60}Co concentrations were less than 0.05 and 0.6 pCi/liter for the suspended and dissolved (filtrate) fractions, respectively. Cesium-137 concentrations in the filtrates ranged from 0.40 to 0.57 pCi/liter, while the average ^{90}Sr concentration was about 0.3 pCi/liter, near the levels that would be expected as a result of fallout.

The results for the water samples collected September 28, 1972, from Barnegat Bay, Oyster Creek and the south fork of Forked River are given in Table 5.5. Since only the filters were analyzed, the reported concentrations refer to suspended radionuclides. The only detectable gamma-ray-emitting radionuclides were ^{54}Mn and ^{60}Co. Manganese-54 and ^{60}Co were found in every sample except that no ^{54}Mn was detected in the sample collected from Barnegat Inlet (P). The station was discharging wastes on September 28, 1972, as indicated by the relatively high ^{54}Mn and ^{60}Co concentrations measured in Oyster Creek and Forked River. The radionuclide concentrations in Barnegat Bay samples were all lower than concentrations in Oyster Creek, and the only bay sample with concentrations higher than in Forked River was taken just north of the river (A). The concentrations in Forked River can be higher than those in Barnegat Bay because wastes discharged into the bay from Oyster Creek can recirculate through Forked River. The bay measurements, however, cannot be related to effluent values from the station because the effects of wind and tide on the dilution of wastes from Oyster Creek into the bay cannot be predicted (see Section 5.1.1). These samples were collected during a period when the station was discharging wastes almost daily, so that radionuclide concentrations in the bay reflect multiple discharges.

The ^{54}Mn and ^{60}Co measurements were not quantitative since only the suspended radionuclides were measured and no data regarding the distribution of radionuclides between suspended and dissolved species in Barnegat Bay are available. Measurements in the discharge canal showed that 66 percent to 96 percent of ^{54}Mn and ^{60}Co discharged to Oyster Creek were associated with suspended material (see Section 4.4.4). These measurements, however, reflect the fraction of ^{54}Mn and ^{60}Co in particulate form in sea water after only a short residence time, and it is possible that the distribution between suspended and dissolved species may change after longer residence times in Barnegat Bay. The measurements do show that insoluble radionuclides can be detected at distances of 3.1 km north and 8.5 km south of Oyster Creek, as well

Table 5.4 Radionuclide Concentrations in Water Samples Collected May 15–16, 1972

Location	Sample vol., l	Suspended solids, mg/l	pH	Salinity g/l	Concentrations, pCi/l ^{90}Sr	 ^{137}Cs
in Forked River (E)	105	18	7.4	18.4	0.32	0.57
in Bay near Waretown (H)	105	17	7.5	20.2	0.32	0.40
in Bay near Gulf Point (L)	107	17	7.3	23.5	0.25	0.44
in Bay near Toms River (M)	105	18	7.3	16.4	NA	NA
in Oyster Creek Channel (N)	210	17	7.4	22.6	NA	NA
in Great Bay	210	28	7.1	28.4	NA	NA

Notes:

1. Letters refer to locations in Figure 5.1.
2. Concentrations of ^{54}Mn and ^{60}Co in filtered solids were <0.05 pCi/liter, and in filtrates <0.6 pCi/liter, in all samples.
3. Concentrations of ^{90}Sr and ^{137}Cs measured in 20-liter volumes of the filtrates.

as in the channel leading into the Atlantic Ocean.

The sampling on September 28, 1972 occurred when levels of radionuclides discharged by the station were unusually high because of problems associated with the waste treatment system.*(5)* During 1972 the station reported discharging 1.8 Ci of ^{60}Co, of which 1.2 Ci (67 percent) was released during August and September of that year.*(5)* Likewise, a total of 0.63 Ci of ^{54}Mn was discharged during 1972, while 0.45 Ci (71 percent) of this total was released during the same two months of 1972.*(5)*

5.2.4 *Hypothetical radionuclide concentrations in the discharge canal (Oyster Creek).* Because concentrations of radionuclides discharged by the station were in most cases near or below minimum detectable levels in the discharge canal and Barnegat Bay water, average water concentrations in Oyster Creek were calculated from data reported by the station.*(5)* The average radionuclide concentrations calculated to be present in Oyster Creek during the period of study are shown in Table 5.6. The average annual concentrations in Oyster Creek in the first three data columns are based on quantities discharged monthly and the total available dilution reported by the station (see Appendix B.4). The station reported the total combined activities of ^{89}Sr and ^{90}Sr for 1971 and 1972. The average concentrations listed in the fourth data column were taken from Table 4.6. These values were calculated from measured concentrations of liquids in the waste sampling tank and the laundry drain tank and the average annual liquid waste volume and the average annual total dilution volume (see Section 4.4.1). No adjustment was made for recirculation.

For the 17 radionuclides for which a comparison of concentrations obtained by the two procedures is possible, 12 agreed within a factor of three. The values of ^{89}Sr, ^{131}I, ^{134}Cs, ^{137}Cs, ^{140}Ba and ^{239}Np differed by a much larger factor. Because concentrations based on monitoring all discharges as reported by the station should be superior to those based on the occasional periodic samples from the waste sample tank, the average concentrations based on the 1971–1973 values reported by the station will be utilized later in this report to indicate the concentration of radionuclides in the aquatic pathways. For those radionuclides not measured by the station, the values obtained from the analysis of liquid wastes prior to discharge and appearing in the last column of Table 5.6 will be used. However, concentrations in Oyster Creek at any time could differ considerably from these averages because reactor wastes are discharged periodically, and the radionuclide composition of these wastes changes with time.

5.3 Radionuclides in Algae and Grass

5.3.1 *Sampling and analysis.* Three species of macro-algae (*Gracilaria verrucosa, Codium fragile, Ulva lactuca*), two aquatic grasses (*Zostera marina, Spartina alterniflora*) and a sponge (*Porifera*) were collected. Ten locations were initially sampled during

Table 5.5 Particulate Radionuclides in Water Samples Collected September 28, 1972

Location-Collection Time	Sample Vol., l	Suspended solids, g/l	pH	Salinity, ppt	Concentrations, pCi/l	
					^{54}Mn	^{60}Co
in Bay near Sunrise Beach, 0920 (O)	151	NA	NA	NA	0.09	0.38
in Bay north of Forked River 1630 (A)	151	80	7.6	25.2	0.99	2.23
in Bay near Waretown, 1000 (H)	151	NA	NA	NA	0.31	0.66
in Bay near Waretown, 1530 (H)	189	49	7.4	25.6	0.55	1.08
in Bay near Gulf Point, 1440 (R)	114	51	7.4	26.6	0.26	0.64
in Bay near Barnegat Inlet, 1400 (P)	378	9	7.6	31.5	0.01	0.07
in Oyster Creek, 1030 (D)	91	15	7.5	24.8	2.19	3.98
South Branch Forked River, 1115 (E)	76	30	7.3	24.1	0.67	1.72

Notes:

1. Letters refer to locations in Figure 5.1; times refer to beginning of collection.
2. Concentrations are based on analysis of cartridge filter.
3. No other photon-emitting radionuclides were detected on filter (< 0.05 pCi/l).
4. Tide: low-tide (0.03 m) at approx. 0810 and high tide (1.65 m) at approx. 1430.
5. Wind: from NE at 10-15 mph.
6. NA - not analyzed.

September and October 1971. Of these, three were selected as sites of sufficient productivity and importance to be resampled three additional times over a 12-month period (April, July and October, 1972) in the bay near the mouth of Oyster Creek (B), at the mouth of Cedar Creek (G) and near Waretown (H) (see Figure 5.1). It was initially planned to use the site in Barnegat Bay at Surf City (I) to obtain background samples, but ^{60}Co and ^{54}Mn were found in samples from there. Background samples, instead, were obtained from Great Bay, 36 km south of Oyster Creek (site X). To determine the extent of the distribution of radionuclides from the station in Barnegat Bay, samples were also collected on October 31, 1972 to November 2, 1972 at the northern extremity of the bay at Sloop Point (N), near the mouth of Toms River (M), and at the southern extremity of the bay in Little Egg Harbor (L).

The samples were dried at 96° C, ashed at 450° C, and analyzed directly by gamma-ray spectrometry with 10- x 10-cm NaI(Tl) detectors, a NaI(Tl) gamma-ray coincidence-anticoincidence spectrometer system, and with 54-cm^{3} or 85-cm^{3} Ge(Li) detectors. Iron was chemically separated, and analyzed for ^{55}Fe with an x-ray proportional detector. The stable elements, Sr, Ca and Fe, were determined with an atomic absorption spectrophotometer. To analyze for volatile radionuclides, particularly ^{3}H, ^{14}C and ^{129}I, aliquots of the fresh sample were analyzed prior to drying and ashing. The analyses for ^{3}H and ^{14}C were made by

Table 5.6 Average Radionuclide Concentration in the Discharge Canal, pCi/l

Radionuclide		Calculated from values reported by station*			Calculated from measured effluent samples,**
		1971	1972	1973	
12.3 -yr	^{3}H	21.1	50.8	31.9	37.7
5730 -yr	^{14}C	NR^{+}	NR	NR	0.0075
14.3 -d	^{32}P	NR	NR	NR	0.056
27.7 -d	^{51}Cr	0.15	0.10	0.40	0.48
313 -d	^{54}Mn	0.42	0.48	0.15	0.39
2.7 -yr	^{55}Fe	NR	NR	NR	0.49
44.6 -d	^{59}Fe	0.05	0.02	0.008	0.063
71.3 -d	^{58}Co	0.10	0.12	0.036	0.047
5.26-yr	^{60}Co	0.79	1.26	0.24	0.81
12.8 -hr	^{64}Cu	NR	NR	NR	0.011
244 -d	^{65}Zn	< 0.011	< 0.036	< 0.011	0.0046
26 -hr	^{76}As	NR	NR	NR	0.045
50.5 -d	^{89}Sr	0.34	0.21	0.18	0.012
28.5 -yr	^{90}Sr			0.024	0.0011
9.7 -hr	^{91}Sr	0.05	0.05	0.002	ND^{+}
65 -d	^{95}Zr	NR	< 0.002	NR	0.015
35.1 -d	^{95}Nb				0.023
66.2 -hr	^{99}Mo	0.11	0.17	0.21	0.14
6.0 -hr	^{99m}Tc	0.10	0.16	0.21	ND
39.6 -d	^{103}Ru	NR	NR	NR	0.011
36 -hr	^{105}Rh	NR	NR	NR	0.043
253 -d	^{110m}Ag	NR	NR	NR	0.0015
60.2 -d	^{124}Sb	0.003	0.003	ND	0.0083
8.06-d	^{131}I	0.38	0.35	0.077	0.12
20.9 -hr	^{133}I	0.28	0.31	0.063	0.041
2.07-yr	^{134}Cs	0.10	1.45	0.074	2.1
30 -yr	^{137}Cs	0.25	2.14	0.073	3.5
12.8 -d	^{140}Ba	0.16	0.054	0.12	0.027
32.4 -d	^{141}Ce	NR	NR	0.005	0.034
284 -d	^{144}Ce	NR	NR	0.018	0.025
235 -d	^{239}Np	0.63	0.48	0.22	0.026

* See Appendix B.4

** Concentrations from Table 4.6

+ NR - not reported; ND - not detected

Note: Approximately 0.6 Ci of ^{133}Xe, 1.8 Ci of ^{135}Xe and small quantities of ^{85m}Kr and ^{88}Kr (< 0.03 Ci) were discharged annually in the water, but aeration would be expected to expel these nuclides.

treating 5-g aliquots of fresh sample in a combustion train, collecting water and CO_2, and measuring the radioactivity with a liquid scintillation counter. The minimum detectable concentrations at the 95 percent confidence level were 250 pCi ^3H/kg fresh weight and an excess of 6.3 dpm ^{14}C/g C above the normal background concentration.

Because of the various drying periods in transit to the laboratory, it was difficult to ascertain appropriate ash weight/wet weight ratios for the algae samples. The state's Bureau of Radiation Protection (BRP) has reported ash weight/fresh weight ratios for four of these species, and the average ratios are significantly lower since its laboratory is so near the collection sites that drying in transit is minimal.*(6)* The following values and standard deviations for this ratio were found:

	Ash weight/fresh weight this laboratory	New Jersey BRP
Codium fragile (17)	0.029 ± 0.014	0.014 ± 0.005
Gracilaria verrucosa (14)	0.085 ± 0.045	0.036 ± 0.008
Ulva lactuca (14)	0.055 ± 0.025	0.027 ± 0.012
Zostera marina (5)	0.028 ± 0.009	0.022 ± 0.003
Spartina alterniflora (10)	0.032 ± 0.007	no value given
Porifera (2)	0.136 ± 0.050	no value given

Notes:

1. The number of samples analyzed is given in parentheses.
2. ± values are the standard deviation of individual measurements.

The agreement for *Z. marina* is to be expected because this grass does not dehydrate as rapidly as the algae. The same is probably true of *Spartina*. To convert the ash weight values given in the following Tables to fresh weight values, it is recommended that the **BRP** ratios be applied to the three species of algae, that this laboratory's ratios be applied to the two species of grass, and one-half the value (0.07) be applied to the *Porifera* samples.

5.3.2 ***Results and discussion of stable element concentrations.*** The concentrations of stable elements measured in the algae and marine plant samples are listed in Table 5.7 according to collection date and site. No significant difference in stable element concentrations was observed in samples collected from the various sites in either Barnegat Bay or Great Bay. These data indicate, as did the water analyses (see Section 5.2.2), that strontium, calcium and potassium are uniformly distributed throughout the bay. The same is true of iron. There does appear to be a decrease in the concentration of strontium, calcium and iron in algae samples collected during the fall of the year. Concentrations averaged 70 percent higher in samples collected during the summer relative to those collected in the fall. This is probably due to a reduced level of or lack of cell division in algae in the colder (11° C) waters of November relative to average summer temperatures (27° C).*(17)* The algae collected in the fall, particularly *C. fragile* and *U. lactuca*, were less abundant and in a poorer condition than in the summer, apparently being in the early stages of cellular degeneration or dead.

The annual average concentrations of stable elements and the Sr/Ca weight ratio measured in each species of algae and grass from all sites are listed in Table 5.8. There are no significant differences in the concentrations of iron, strontium or calcium in the various species of algae and grasses, only in potassium.

The Sr/Ca weight ratio in the marine plants is the same as that measured in the water (see Section 5.2.2), *i.e.*, OR* = 1. Except possibly for *C. fragile*, the Sr/Ca ratios in the algae are less than that observed in the water. The average OR in these species of algae is about 0.6, indicating either an affinity for calcium or discrimination against strontium. This observation is consistent with the mean concentration factors (CF) tabulated below which, at equilibrium, is defined as $(\text{mg/kg fresh weight})_{sample} \div (\text{mg/liter})_{water}$.

Species	Concentration factors Fe†	Sr	Ca	K
C. fragile	3,200	0.8 ± 0.3	0.9 ± 0.3	1.6 ± 0.5
G. verrucosa	6,300	1.0 ± 0.3	1.6 ± 0.8	34 ± 8
U. lactuca	5,400	0.9 ± 0.4	1.7 ± 0.9	7 ± 2
Spartina	4,000	1.4 ± 0.2	1.8 ± 0.9	17 ± 4
Z. marina	8,400	1.9 ± 0.4	1.9 ± 0.4	6 ± 2

†An estimate assuming a water concentration of 0.04 mg Fe/liter (see Section 5.2.2).

Notes:

1. Concentrations in mg/g ash were converted to mg/kg fresh weight by using the ratios in Section 5.3.1.
   Concentrations in water were taken from Table 5.1.
2. ± values are standard deviations of individual observations.

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*OR (Observed Ratio) = $(Sr/Ca)_{sample} \div (Sr/Ca)_{water}$

Table 5.7 Stable Ion Concentrations in Algae and Marine Plants, mg/g Ash

Sample No.	Collection Date	Sample*	Ca	Sr	Fe	K**
		Bay at mouth of Oyster Creek (B)**				
4	Sept. 23, 1971	C	9.5	0.37	2.2	35
5	Sept. 23, 1971	G	4.0	0.09	4.2	212
6	Sept. 23, 1971	Z	8.4	0.20	8.9	46
9	Oct. 18, 1971	S	11.0	0.37	2.3	63
30	April 12, 1972	U	11.0	0.19	10.0	84
45	July 12, 1972	C	19.0	0.22	15.6	27
44	July 12, 1972	G	22.2	0.23	12.7	271
46	July 12, 1972	U	22.3	0.25	13.2	52
43	July 12, 1972	S	27.1	0.22	6.8	87
58	Nov. 1, 1972	C	16.8	0.23	7.1	20
60	Nov. 1, 1972	G	9.3	0.12	5.6	256
59	Nov. 1, 1972	U	5.6	0.08	7.3	40
61	Nov. 1, 1972	S	15.9	0.25	1.9	104
		Bay near mouth of Cedar Creek (G)				
26	Oct. 21, 1971	C	23.8	0.42	4.9	25
25	Oct. 21, 1971	G	10.2	0.41	8.9	123
32	April 19, 1972	C	19.9	0.50	12.1	25
31	April 19, 1972	U	25.2	0.21	10.8	60
50	July 12, 1972	C	15.7	0.20	10.9	19
49	July 12, 1972	G	14.1	0.13	10.0	170
48	July 12, 1972	U	30.9	0.31	17.9	45
63	Nov. 1, 1972	C	NA†	NA	15.4	26
65	Nov. 1, 1972	G	8.0	0.10	2.2	212
64	Nov. 1, 1972	U	9.8	0.14	10.5	55
		Bay at Waretown (H)				
28	April 18, 1972	C	21.2	0.38	6.4	22
29	April 18, 1972	U	20.4	0.23	6.5	70
42	July 11, 1972	C	14.3	0.21	16.3	51
40	July 11, 1972	G	11.8	0.12	13.5	224
39	July 11, 1972	U	31.7	0.15	4.5	52
55	Nov. 1, 1972	C	11.1	0.17	5.9	17
57	Nov. 1, 1972	G	13.1	0.14	3.1	142
56	Nov. 1, 1972	U	NA	0.12	NA	28
		Bay off Island Beach (C)				
7	Sept. 23, 1971	C	12.9	0.37	3.4	21
8	Sept. 23, 1971	Z	19.1	0.30	12.6	61
22	Oct. 21, 1971	C	5.9	0.31	7.0	15
23	Oct. 21, 1971	Z	12.9	0.41	12.0	31

Table 5.7 Stable Ion Concentrations in Algae and Marine Plants, mg/g Ash (Cont'd)

Sample No.	Collection Date	Sample*	Ca	Sr	Fe	K++
		Bay between Oyster Creek and Forked River (F)				
12	Oct. 19, 1971	C	4.0	0.14	8.1	25
13	Oct. 19, 1971	G	7.5	0.14	4.0	145
14	Oct. 19, 1971	P	2.0	0.07	8.8	15
		Bay at mouth of Forked River (A)				
2	Sept. 23, 1971	C	4.3	0.06	10.6	40
		South Branch of Forked River (E)				
10	Oct. 21, 1971	G	35.8	0.37	10.0	153
11	Oct. 21, 1971	S	7.4	0.20	3.6	45
		Bay at Sloop Point (N)				
67	Nov. 2, 1972	G	9.7	0.11	4.3	153
66	Nov. 2, 1972	U	12.0	0.13	7.7	71
		Bay near Toms River (M)				
68	Nov. 2, 1972	C	NA	NA	8.2	31
		In Cedar Creek (K)				
24	Oct. 21, 1971	S	10.5	0.29	3.4	70
47	July 12, 1972	S	6.4	0.22	1.2	94
		Bay off Surf City (I)				
16	Oct. 20, 1971	C	4.5	0.07	4.4	11
18	Oct. 20, 1971	Z	21.5	0.32	15.0	20
15	Oct. 20, 1971	P	23.8	0.53	1.5	18
		Little Egg Harbor (L)				
53	Oct. 31, 1972	U	10.5	0.14	3.7	57
		Great Bay (X)				
22	April 19, 1972	U	11.9	0.15	3.7	47
33	July 10, 1972	U	9.4	0.14	9.5	65
35	July 10, 1972	G	5.0	0.12	8.1	188
36	July 10, 1972	F	18.8	0.13	10.1	162
38	July 10, 1972	S	9.3	0.19	11.2	104
51	Oct. 31, 1972	U	6.6	0.07	2.7	43
54	Oct. 31, 1972	S	15.9	0.23	2.8	60

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* Samples: C-*Codium fragile*, G-*Gracilaria verrucosa*, U-*Ulva lactuca*, S-*Spartina alterniflora*, Z-*Zostera marina*, P-*Porifera*, F-*Fuca*.

** Locations: See Figures 5.1 and 5.2.

* NA - not analyzed

** Based on 848 pCi ^{40}K/gK

Note: The standard deviation for the K, Ca, Sr and Fe values is approximately 5%.

Table 5.8 Average Stable Element Concentration in Algae and Marine Plants, mg/g Ash

Species	K	Fe	Sr	Ca	Sr/Ca
C. fragile (16)	24 ± 7	9 ± 4	0.23 ± 0.11	14 ± 7	0.018 ± 0.009
G. verrucosa (12)	187 ± 47	7 ± 3	0.18 ± 0.10	15 ± 11	0.014 ± 0.005
U. lactuca (14)	55 ± 14	8 ± 4	0.17 ± 0.07	14 ± 7	0.013 ± 0.003
Spartina (8)	78 ± 22	5 ± 3	0.24 ± 0.06	13 ± 6	0.022 ± 0.009
Z. marina (4)	40 ± 17	12 ± 2	0.31 ± 0.08	15 ± 6	0.022 ± 0.009

Notes:

1. Number of samples are given in parentheses.
2. ± values are standard deviations of individual measurements.

The concentrations of strontium and calcium in water were taken from Table 5.1 for the date and site which corresponded to the algae or grass sample. As the concentration of iron in the water samples was below the minimum detectable level, a value of 0.04 mg Fe/liter that was computed in Section 5.2.2 was used in these calculations. The average potassium concentration measured in the four July water samples, 200 ± 15 mg/liter, was assumed uniform with respect to time and used to calculate CF's for potassium (see Section 5.2.2).

Concentration factors for algae determined in this study compare as follows with those previously published for marine algae:

Source	Concentration factors Sr	Ca	Fe	K
This Study, mean	0.9 ± 0.3	1.4 ± 0.7	5,000 ± 1,600	14 ± 16
Reference 11	0.9 – 20	8	50,000	26
Reference 18	0.2 – 82	1.8 – 31	300 – 6,000	4 – 31
Reference 19, 20	0.1 – 90	2	1,000 – 5,000	...
Reference 15	1 – 3	...	730	50
Reference 12	2	4	...	4

Since CF's in the literature are frequently reported for algae without indicating species, only a gross comparison can be made. Values reported by Bryan *et al* and Polikarpov refer to *Ulva lactuca* and *Ulva rigida*, respectively *(12,15)*.

The CF's determined in this study are similar to, or fall within the range, of those previously established. Because the factors in this study are based on annual average concentrations, they may tend to be low relative to CF's based solely on data collected during the summer when the growth rate was greatest and the concentrations highest.

These factors indicate that algae and plants are generally good indicators of iron in the marine environment. Their usefulness for indicating potassium levels depends upon the species, while for strontium and calcium, the concentration factors are not significant for the species studied.

5.3.3 *Results and discussion of radionuclide concentrations.* The concentrations of relatively long-lived radionuclides measured in samples of marine flora are listed in Table 5.9 according to collection date and sampling site. The two predominant radionuclides attributable to the station are ^{54}Mn (above concentrations of 0.2-0.3 pCi/g) and ^{60}Co. Cobalt-58 and ^{137}Cs were detected in samples collected in July and November 1972 at all three principal sampling sites (B, G and H). In addition, ^{51}Cr was detected in two *Spartina* samples collected from the discharge canal in July and November 1972 at 5 ± 1 pCi/g and 3 ± 1 pCi/g, respectively. No tritium was detected in algae. The minimum detectable level (3σ) was 200 pCi/liter of loose water or 250 pCi/kg fresh weight. Water of combustion was about 80 percent of fresh weight. The

Table 5.9 Radionuclide Concentrations in Algae and Marine Plants, pCi/g Ash

Collection Date	Sample*	^{54}Mn	^{58}Co	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{141}Ce	^{144}Ce
Bay, at mouth of Oyster Creek (B)												
Sept. 23, 1971	C	5.6	< 0.5**	7.7	0.40	1.8	3.6	4.7	< 0.4	< 0.4	NA†*	NA
Sept. 23, 1971	G	8	< 1.1	18	0.80	NA	NA	5.9	< 0.9	< 1.0	NA	NA
Sept. 23, 1971	Z	9	< 2.6	13	1.2	NA	NA	NA	< 2.0	< 2.0	NA	NA
Oct. 18, 1971	S	5	2.6	11	0.05	< 0.5	1.0	5.4	< 0.8	< 0.8	NA	NA
April 18, 1972	U	1.9	< 0.6	2.5	< 0.05	< 1.2	3.5	3.9	< 0.5	1.5	1.7	4.0
July 12, 1972	C	4.3	< 0.6	12	0.05	1.6	2.4	3.2	< 0.5	< 0.6	1.3	2.9
July 12, 1972	G	4.2	0.6	11	0.11	2.6	2.1	4.9	< 0.2	0.7	1.0	2.4
July 12, 1972	U	2.3	0.3	5.2	0.10	1.5	1.2	3.2	0.15	0.5	0.6	1.7
July 12, 1972	S	4.8	1.1	8.7	0.21	2.9	4.2	3.5	0.52	1.0	1.0	1.9
Nov. 1, 1972	C	2.4	0.3	9.6	0.34	< 1.0	< 0.6	NA	< 0.4	< 0.5	< 0.3	1.0
Nov. 1, 1972	G	3.8	0.5	14.7	0.10	< 0.8	< 0.6	NA	0.55	1.4	< 0.2	< 0.6
Nov. 1, 1972	U	4.4	0.5	17.9	0.06	< 1.0	< 0.8	NA	< 0.3	< 0.4	< 0.3	1.0
Nov. 1, 1972	S	3.6	0.4	10.9	0.27	0.5	0.8	NA	1.2	2.5	< 0.2	1.2
Bay, near mouth of Cedar Creek (G)												
Oct. 21, 1971	C	7.2	< 0.7	9	0.11	NA	NA	3.1	< 0.9	< 0.8	NA	NA
Oct. 21, 1971	G	14	< 2.0	16	0.28	< 2.0	4.0	7.6	< 2.0	< 2.0	NA	NA
April 19, 1972	C	2.7	< 0.5	3.1	0.06	< 0.9	1.2	2.9	< 0.5	1.0	0.8	3.4
April 19, 1972	U	2.6	< 0.6	4.0	< 0.05	2.6	1.0	5.0	< 0.6	0.6	1.1	4.2
July 12, 1972	C	1.6	0.2	3.4	0.06	1.0	1.0	2.7	< 0.2	0.2	0.4	1.3
July 12, 1972	G	3.6	0.3	7.0	0.53	2.3	0.9	3.1	< 0.2	0.3	0.8	2.9
July 12, 1972	J	2.8	< 0.5	7.3	0.13	1.1	1.6	3.1	< 0.3	0.5	0.7	2.0
Nov. 1, 1972	C	5.3	0.5	18	0.10	< 0.5	0.7	NA	< 0.2	0.6	< 0.2	1.2
Nov. 1, 1972	G	4.4	0.4	13	0.17	< 0.4	0.5	NA	0.43	1.0	< 0.3	0.7
Nov. 1, 1972	U	5.2	0.4	16	0.06	< 0.4	0.3	NA	0.17	0.5	< 0.2	0.8
Bay, at Waretown (H)												
Oct. 20, 1971	C	8	< 1.0	16	0.12	< 1.8	2.1	6.5	< 1.1	< 1.0	NA	NA
Oct. 20, 1971	G	11	< 1.3	25	NA	< 1.0	1.4	7.0	< 1.0	1.5	NA	NA
April 18, 1972	C	1.1	< 0.3	4.0	< 0.05	1.9	0.9	3.5	< 0.2	0.5	0.9	3.3

Table 5.9 Radionuclide Concentrations in Algae and Marine Plants, pCi/g Ash (Cont'd)

Collection Date	Sample*	^{54}Mn	^{58}Co	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{141}Ce	^{144}Ce
April 18, 1972	U	0.9	<0.5	2.5	0.11	10.6	7.5	3.9	<0.5	2.1	3.1	6.1
July 11, 1972	C	2.0	0.3	5.9	<0.05	1.2	2.0	3.9	<0.1	0.2	0.8	2.6
July 11, 1972	G	3.7	0.3	7.6	0.14	1.8	1.9	4.7	<0.1	0.3	0.7	1.7
July 11, 1972	U	1.5	0.4	5.6	0.09	0.8	1.0	1.6	<0.2	<0.2	0.5	1.3
Nov. 1, 1972	C	1.3	<0.4	4.8	0.08	<0.8	<0.5	NA	<0.2	<0.3	<0.2	<0.5
Nov. 1, 1972	G	6.3	0.6	22	NA	<0.6	0.7	NA	0.30	0.7	<0.3	0.6
Nov. 1, 1972	U	1.7	<0.3	8.2	0.10	<0.7	<0.5	1.6	<0.2	<0.3	<0.2	0.6
				Bay, off Island Beach (C)								
Sept. 23, 1971	C	5.6	<0.6	1.9	0.10	<0.7	1.0	3.5	<0.5	<0.5	NA	NA
Sept. 23, 1971	Z	26	<1.0	7.6	0.70	3.1	5.8	12	<1.1	<1.0	NA	NA
Oct. 21, 1971	C	2.9	<0.6	1.0	0.08	NA	NA	3.4	<0.7	<0.6	NA	NA
Oct. 21, 1971	Z	20	<1.0	6.1	0.20	<1.5	2.8	6.4	<1.0	<1.2	NA	NA
				Bay, between Oyster Creek and Forked River (F)								
Oct. 19, 1971	C	7.2	<0.9	12	0.06	NA	NA	6.1	<0.7	<0.8	NA	NA
Oct. 19, 1971	G	11	<0.9	17	0.12	<1.8	1.4	2.4	<0.8	<1.0	NA	NA
Oct. 19, 1971	P	1.3	<0.8	2.1	NA	NA	NA	3.5	<0.6	<0.6	NA	NA
				Bay, at mouth of Forked River (A)								
Sept. 23, 1971	C	23	<1.0	39	0.3	NA	NA	12	<1.0	<1.0	NA	NA
Sept. 23, 1971	G	22	<3.0	45	0.13	NA	NA	NA	<2.1	<2.0	NA	NA
				South Branch of Forked River (E)								
Oct. 21, 1971	G	13	<0.7	29	0.08	NA	NA	8.0	<0.7	<0.8	NA	NA
Oct. 21, 1971	S	2.0	<1.2	0.5	0.10	<2.0	2.4	3.6	<1.4	<1.3	NA	NA
				Bay, at Sloop Point (N)								
Nov. 2, 1972	G	4.7	0.4	16	0.13	<0.5	0.9	NA	0.20	0.9	<0.2	1.2
Nov. 2, 1972	U	0.3	<0.3	1.1	0.08	0.2	0.6	NA	<0.1	0.4	<0.2	1.3
				In Toms River (J)								
Oct. 21, 1971	S	<0.5	<0.6	<0.2	0.20	1.2	2.5	3.5	<0.4	0.9	NA	NA
				Bay, near Toms River (M)								
Nov. 2, 1972	C	1.7	<0.3	6.6	0.10	<0.4	0.5	NA	<0.2	0.3	<0.3	<0.7
Nov. 2, 1972	Z	0.4	<0.2	0.8	0.13	<0.3	0.3	NA	<0.1	0.2	<0.2	0.4

Table 5.9 Radionuclide Concentrations in Algae and Marine Plants, pCi/g Ash (Cont'd)

Collection Date	Sample*	^{54}Mn	^{58}Co	^{60}Co	^{90}Sr	^{95}Zr	^{95}Nb	^{106}Ru	^{134}Cs	^{137}Cs	^{141}Ce	^{144}Ce
					In Cedar Creek (K)⁺							
Oct. 21, 1971	S	<0.4	<0.8	<0.3	0.11	<2.0	1.9	1.5	<1.1	<1.1	NA	NA
July 12, 1972	S	0.2	<0.1	0.2	0.12	5.0	6.4	1.6	<0.1	0.5	1.9	3.4
Nov. 1, 1972	S	<0.4	<0.4	<0.6	0.19	<0.6	1.1	NA	<0.3	0.9	<0.3	2.2
					Bay, off Surf City (I)							
Oct. 20, 1971	C	1.0	<0.4	0.4	0.11	<0.5	0.6	2.5	<0.5	<0.4	NA	NA
Oct. 20, 1971	Z	8.3	<2.0	5.0	0.37	NA	NA	6.0	<1.0	<1.0	NA	NA
Oct. 20, 1971	P	<1.0	<1.0	<0.5	0.12	<1.8	2.1	4.9	<1.0	<1.0	NA	NA
					Little Egg Harbor (L)							
Oct. 31, 1972	U	0.2	<0.2	0.2	0.09	<0.2	0.10	NA	<0.1	0.1	<0.2	1.4
					Great Bay (X)							
April 19, 1972	U	<0.3	<0.3	<0.2	0.08	1.8	1.0	1.3	<0.2	0.3	1.2	1.9
July 10, 1972	U	<0.3	<0.5	<0.2	0.12	1.1	0.7	1.4	<0.2	0.2	0.4	0.9
Oct. 31, 1972	U	<0.2	<0.2	<0.2	0.06	<0.7	0.2	NA	<0.1	<0.2	<0.2	<0.4
July 10, 1972	G	<0.5	<0.5	<0.2	0.12	<1.4	1.9	1.6	<0.1	0.2	0.4	1.5
July 10, 1972	S	0.2	<0.3	<0.2	0.25	1.7	2.2	1.7	<0.1	0.3	0.3	1.4
Oct. 31, 1972	S	<0.4	<0.5	<0.5	0.10	<0.7	<0.5	NA	<0.1	0.3	<0.4	<1.0
July 10, 1972	F	0.3	<0.2	0.2	0.13	3.1	3.5	2.6	<0.1	0.4	0.3	1.0

* Samples: C-Codium fragile, G-Gracilaria verrucosa; U-Ulva lactuca; S-Spartina alterniflora; Z-Zostera marina; P-Porifera; F-Fuca.

**< values are 3σ of the counting error; the ± 2σ counting errors are 30% for ^{58}Co, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{134}Cs, ^{137}Cs and ^{144}Ce; 20% for ^{54}Mn, ^{106}Ru and ^{141}Ce, and 10% for ^{60}Co.

⁺ Locations: see Figures 5.1 and 5.2.

⁺⁺Not Analyzed.

Notes:

1. Minimum detectable levels (3σ) for those nuclides not (rarely) detected, pCi/gm ash weight except ^{3}H, pCi/kg fresh weight:

^{3}H	^{51}Cr	^{55}Fe	^{59}Fe	^{65}Zn	^{103}Ru
250	2.3	3	2	0.8	0.3

2. Mean ^{14}C concentration = 17.5 ± 1.3 dpm/gC.

inability to detect ^{3}H in these samples is expected since the concentration factor for tritium is near 1 and the water concentration is probably less than 100 pCi/l (about 5 pCi/l in sea water, 150 pCi/l in fresh water and the 40 pCi/l contributed by the station, see Table 4.6.*(15)* The ^{14}C concentrations in algae and grass collected near the mouth of the discharge canal did not significantly exceed the concentrations in comparable samples from Great Bay. The mean ^{14}C concentration was 17.5 ± 1.3 dpm/g C. This value is within the range of the normal specific activity of ^{14}C that has resulted from cosmic ray bombardment of nitrogen in the upper atmosphere and fallout from thermonuclear detonations, 17 ± 2 dpm/g C.*(22)* Additional natural and fallout radionuclides observed in some samples were ^{7}Be, ^{40}K, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{137}Cs, ^{141}Ce and ^{144}Ce.

No significantly consistent difference in ^{54}Mn or ^{60}Co concentrations in algae was observed among the three principal sampling locations. This indicates considerable movement of radionuclides north along the coast from Oyster Creek, even though the channel across the bay to Barnegat Inlet extends eastward from about Waretown, south of Oyster Creek (see Section 5.1.1). Samples collected at 11 different sites indicated contamination of algae throughout Barnegat Bay. Above-ambient concentrations of ^{54}Mn and ^{60}Co were measured in samples collected from the south end of Little Egg Harbor (L), the southern extremity of Barnegat Bay, from the east side of the bay at Island Beach (C) and Surf City (I), and from Toms River (M) and Sloop Point (N), in the northern part of the bay (see Figure 5.2). Cesium-134 and ^{58}Co were also detected in a sample of *G. verrucosa* from the latter site. Relatively high levels of ^{60}Co, ^{54}Mn, ^{134}Cs, ^{58}Co, and ^{51}Cr were observed in *Spartina* that had grown in the mouth of the discharge canal. However, only background concentrations of fallout radionuclides were detected in *Spartina* collected from the mouths of Cedar Creek (K) and Toms River (J). Hence, although radioactivity from the station is dispersed throughout the bay, it apparently does not enter the creeks and rivers emptying into the bay in detectable amounts. An exception to this is Forked River, 1.6 km north of the discharge canal, which is used by the station as the coolant water intake. Algae and *Spartina* samples from the south branch of Forked River (E) contained both ^{54}Mn and ^{60}Co. This confirms earlier reports that radionuclides recirculate in coolant water (see Section 5.1.4).

No contamination was detected in samples from Great Bay, immediately south of Barnegat Bay, which was used as the background site for this study. Fuca, an algae not observed growing in Barnegat Bay, contained, in addition to relatively higher concentrations of the normally observed fallout radionuclides, small amounts of ^{54}Mn and ^{60}Co that may be due to fallout.

Because the radionuclide concentrations were not significantly different in samples from the three principal sites, the concentrations there were averaged for each species based on fresh weight, using the appropriate ash weight/fresh weight ratios given in Section 5.3.1. The average concentrations are listed in Table 5.10. Although species cannot be consistently ranked by radionuclide concentration, the highest concentrations were usually observed in *G. verrucosa*, followed by *U. lactuca* containing about one-half as much activity, and then *C. fragile*. A similar ranking was indicated by McCurdy.*(7)*

Except for ^{54}Mn and ^{60}Co, concentrations in *Spartina* approach those observed in *G. verrucosa*. Because of dilution in the bay, the *Spartina* that grew in the discharge canal was exposed to higher concentrations of radionuclides from the station than the algae in the bay, which would indicate a relatively lower uptake by the *Spartina*. *Zostera marina*, another rooted plant that grows submerged in the bay, reflected a high affinity for both ^{54}Mn and ^{60}Co. Samples collected at Island Beach (C) and Surf City (I), 10 km and 17 km, respectively, from Oyster Creek, contained easily detectable quantities of ^{54}Mn, 650 pCi/kg, and ^{60}Co, 190 pCi/kg. These concentrations are 10 times those measured in *C. fragile* collected concurrently from the same sites. High absorption through the root system might account for the observed uptake, as the concentrations of ^{54}Mn and ^{60}Co in the root system of *Z. marina* has been found to be twice that in the stem.*(6)*

The ^{40}K concentrations in algae were strongly species dependent and constant throughout the growing season. *G. verrucosa* contained 4–6 times the ^{40}K content as *U. lactuca*, which normally contained about 4 times the amount in *C. fragile*. These large differences were not observed of ^{137}Cs, but the species rank was the same.

The large standard deviations assigned to some of the average concentrations tabulated in Table 5.10 are due in part to observed seasonal variations. A trend of increasing concentration from a low in spring samples to the highest levels in fall was observed for ^{7}Be, ^{54}Mn, ^{58}Co, ^{60}Co, ^{134}Cs and, in some species, ^{137}Cs. In fact, ^{7}Be, ^{58}Co and ^{134}Cs were not detected in any spring samples, and the latter two were detected only at site B in the summer samples. They were observed, however, at all three sites in samples collected in the fall, including *G. verrucosa* at site N. Radionuclides found to be in

Table 5.10 Average Concentration of Radionuclides in Species of Algae and Spartina Collected from the Three Principal Sampling Sites in Barnegat Bay, pCi/kg Fresh Weight

Nuclide	*C. fragile*	*G. Verrucosa*	*U. lactuca*	*Spartina**
^{7}Be	40 ± 20	180 ± 80	70 ± 20	420 ± 320
^{14}C**	18 ± 1	17 ± 2	18 ± 2	16 ± 2
^{40}K	320 ± 80	6300 ± 1400	1200 ± 300	2300 ± 500
^{54}Mn	50 ± 30	240 ± 120	70 ± 30	140 ± 30
^{60}Co	120 ± 50	540 ± 210	120 ± 50	320 ± 40
^{90}Sr	1.1 ± 0.4	5.4 ± 2.5	2.4 ± 1.0	6.1 ± 2.9
^{95}Zr	14 ± 8	50 ± 30	30 ± 20	40 ± 30
^{95}Nb	20 ± 14	40 ± 20	30 ± 20	60 ± 60
^{103}Ru^{+}	10 ± 3	30 ± 7	20 ± 5	20 ± 15
^{106}Ru	50 ± 17	200 ± 60	100 ± 30	140 ± 40
^{137}Cs	7 ± 4	30 ± 20	20 ± 10	40 ± 30
^{141}Ce^{++}	11 ± 4	30 ± 7	30 ± 20	20 ± 10
^{144}Ce	30 ± 14	60 ± 40	60 ± 40	50 ± 15

* Sites B, G and H; average for Spartina from Site B only.

** Concentrations given as dpm ^{14}C/gC.

+ Detected only in samples collected July 1972; for other periods, < 7 pCi/kg.

++ Not detected in samples collected Nov. 1972; < 7 pCi/kg.

Notes:

1. < values averaged as one half the value.
2. ± values are standard deviations of individual observations.

highest concentration in spring and lowest in fall include ^{95}Zr, ^{95}Nb, ^{141}Ce and ^{144}Ce, while ^{103}Ru was detected only in the samples collected during the summer. Variation in radionuclide concentration may result from any one or a combination of the following:

1) The growing period of the algae or grass — during April only *U. lactuca* and small amounts of *C. fragile* were observed. In July, all species were abundant, and in October and November, *U. lactuca* had nearly disappeared and the *C. fragile* appeared to be in poor condition. Hence, radionuclide uptake may vary with stage of activity.
2) Because the station discharges in batches rather than at a constant rate, sampling would produce different results depending upon the time of discharge and turnover rates of radionuclides in algae.
3) Atmospheric fallout varies with the season of the year, usually being highest in spring.

The second factor listed above is probably responsible for the higher levels of certain radionuclides in fall samples because these were discharged at higher levels during the second half of 1972, whereas, concentration of stable element which are relatively constant with time in the water decreased in fall samples (see Section 5.3.2). For those radionuclides discharged by the plant, the uptake or loss of nuclides by the flora is governed to some extent by seasonal growth and degeneration, but the availability of radionuclides for uptake will depend upon plant discharges.

Listed in Table 5.11 are the average background concentrations based on the samples collected from Great Bay (see Table 5.9) and the ash weight/fresh weight ratios given in Section 5.3.1. Comparing these background concentrations with average radionuclide concentrations listed above for the three principal sites, the only radionuclides, in addition to ^{54}Mn, ^{58}Co, ^{60}Co and ^{134}Cs, routinely observed to exceed significantly the background were ^{106}Ru and ^{137}Cs in all species and ^{7}Be

Table 5.11 Radionuclide Concentrations in Algae and Spartina Samples from Great Bay (Background Area), pCi/kg Fresh Weight

Nuclide	U. lactuca	G. verrucosa	Spartina
^{7}Be	60	126	67
^{14}C*	18	18	17
^{54}Mn	<8	18	12
^{58}Co	<9	18	12
^{60}Co	10	<7	11
^{90}Sr	2	4	7
^{95}Zr	27	50	32
^{95}Nb	17	68	47
^{103}Ru	15	27	42
^{106}Ru	56	58	54
^{134}Cs	<5	<4	4
^{137}Cs	6	7	11
^{141}Ce	16	14	11
^{144}Ce	56	54	38

Note: No C. fragile was observed growing in Great Bay.

*Concentrations given as dpm ^{14}C/gC.

in the *Spartina*. The concentration of those radionuclides contributed by the station are as follows:

Species	Concentration, pCi/kg ^{137}Cs	 ^{106}Ru	 ^{7}Be
U. lactuca	14 ± 11	60 ± 30	---
G. verrucosa	23 ± 18	140 ± 60	---
*C. fragile**	5 ± 4	30 ± 17	---
Spartina	30 ± 30	90 ± 40	350 ± 320

*Background activity assumed to be in same ratio to other algae samples as observed in Barnegat Bay samples.

Strontium-90 was measured in excess of the background concentration only in the following samples:

Collection date	Site	Excess ^{90}Sr, pCi/kg *G. verrucosa*	 *Z. marina*
Sept. 23, 1971	B	20 ± 10	24 ± 10
Sept. 23, 1971	C	---	20 ± 6
Oct. 21, 1971	G	6 ± 4	---
July 12, 1972	G	15 ± 6	---

Uptake of ^{54}Mn and ^{60}Co by algae can be compared by observing the ^{60}Co/^{54}Mn activity ratios. This ratio did not vary significantly between samples from sites near the discharge canal (B, G, H, F, A, E) for any one sampling period. Differences in the activity ratio were observed in samples collected at different times, as shown in the second column of the following tabulation. The ^{60}Co/^{54}Mn activity ratio was similar in samples collected during the first three sampling periods; however, the ratio was significantly higher in those collected during the fall of 1972. The activity ratio in the *Spartina* samples from Oyster Creek were similar to those listed for algae.

Date	^{60}Co/^{54}Mn Activity Ratio algae	 effluent*
Oct.-Nov. 1971	1.9 ± 0.4**	1.7
April 1972	2.1 ± 0.8	2.4
July 1972	2.5 ± 0.5	2.0
Nov. 1972	3.8 ± 0.6	3.7

* Average of month sampled and previous month.

** ± values are standard deviations of individual ratios.

The last column above lists the average ^{60}Co/^{54}Mn activity ratio in station effluents during the month sampled and the previous month (see Appendix B.4). The similarity between the ^{60}Co/^{54}Mn ratio in algae and in the station effluent is obvious, and the much larger activities discharged by the station during August, September and October 1972 are also reflected in the algae measurements. These close correlations, if real, suggest that ^{54}Mn and ^{60}Co act similarly in the aqueous environment of the discharge canal and bay, and are adsorbed similarly by algae. These data also suggest that algae adsorb ^{60}Co and ^{54}Mn from the water as the station discharges these nuclides, and not from dissolved ^{54}Mn and ^{60}Co that had been deposited earlier in the sediment. The ^{60}Co/^{54}Mn activity ratio measured in sediment near the mouth of Oyster Creek during this study was about 6 (see Section 5.7.4), similar to the ratio reported by McCurdy and much higher than that observed in the algae or grasses.*(6)*

At all sampling points along the west coast of Barnegat Bay, at Sloop Point (N) and in Little Egg Harbor (L), ^{60}Co activity exceeded that of ^{54}Mn in samples of algae, grasses (except in one sample of *Spartina* from Forked River, E), sediment and water. However, along the east side of the bay, the ^{54}Mn concentrations exceeded those of ^{60}Co in every case. At Island Beach State Park (C), the average ^{60}Co/^{54}Mn ratio in two samples of *C. fragile* and *Z. marina* was 0.32 ± 0.02, and at Surf City (I), the ratio in one sample of each was 0.50 ± 0.14. Samples from Island Beach State Park were reported by McCurdy to contain similar activity ratios of 0.13 to 0.42 for the same two species *(6)*. The reason for these high ^{54}Mn concentrations relative to ^{60}Co along the east shore of the bay is not known, but may be the result of an earlier, higher level discharge of ^{54}Mn.

No differences were observed in the ^{58}Co/^{60}Co ratio in algae collected during the same period at sites B, G and H. However, the average ratio in algae collected in July 1972, 0.054 ± 0.010, was twice that observed in the November 1972 samples, 0.029 ± 0.003. The activity ratio in station effluent during 1972 was about twice that measured in algae, which suggests that most of the cobalt had been in the environment for an average time of about 70 days.

In samples containing ^{134}Cs, the ^{134}Cs/^{137}Cs activity ratio did not appear to vary significantly with species, location or season. Subtracting a background ^{137}Cs concentration of 0.2 pCi/g ash, the average ^{134}Cs/^{137}Cs activity ratio was 0.53 ± 0.05, similar to the ratio of 0.6 in effluent (see Table 5.6). In April of 1972, the ^{134}Cs/^{137}Cs ratio in sediment near the mouth of the discharge canal was reported to be 0.25 ± 0.08 *(7)*. Earlier discharges may account for the low ^{134}Cs/^{137}Cs ratio of 0.22, measured in the algae sample from Sloop Point, about 29 km north of Oyster Creek.

Concentration factors (CF) for all radionuclides measured in algae and water-grass samples cannot be determined because most were not measurable in water. Also, it was not possible to estimate the concentrations in the bay water from the radioactivities discharged by the station because the amount of dilution in the bay is not known (see Section 5.1.1). Concentration factors are thus given for only the two radionuclides measured in water, ^{90}Sr and ^{137}Cs (see Table 5.3).

The range and average CF's calculated for each species of algae and *Spartina* over a one-year period are:

	Concentration factors			
	^{90}Sr		^{137}Cs	
Species	range	average	range	average
C. fragile	0.4 – 16	3 ± 3	1.5 – 11	5 ± 4
G. verrucosa	2 – 73	20 ± 18	6 – 36	20 ± 13
U. lactuca	1 – 13	5 ± 4	7 – 32	14 ± 8
Spartina	1 – 35	15 ± 13	12 – 40	23 ± 12

Note: ± values are standard deviations of the individual factors.

These factors were calculated by dividing the concentration measured in the algae sample (pCi/kg fresh weight) by that measured in a water sample (pCi/liter) collected at the same site and time.

These CF's vary considerably as indicated by the range and large standard deviations. This is largely due to the two or three measured water concentrations at each location not being representative of the concentration associated with the algae during most of its growing period and variations in uptake with seasonal growth characteristics of the algae (see Section 5.3.3). The factors calculated for radiostrontium are generally higher than those calculated for stable strontium (see Section 5.3.2). The factors for stable strontium reflect equilibrium conditions while those for ^{90}Sr may be in response to higher ^{90}Sr concentrations.

The average CF's for ^{90}Sr and ^{137}Cs, including all samples of algae and *Spartina*, are of the same order of magnitude as the previously published values listed below.

	Published CF's	
Reference	^{90}Sr	^{137}Cs
11	12.5	20
18	0.2 – 82	87 – 240
19	0.1 – 9	16 – 20
20	96	
This study	15 ± 8	16 ± 8

5.3.4 Significance of radionuclides in marine algae and grasses. Although these algae and grasses are not consumed by man, they are an important type of sample for surveillance of aquatic environments because:

1) They provide a source of radionuclides to the aquatic environment. Upon death and decay, radionuclides are released to the water or become available to invertebrates in the sediment that are fed upon by fish and other large aquatic organisms.
2) Many species of algae are consumed by organisms in the food chain effecting an increase in the uptake of radionuclides by man.
3) They concentrate biologically significant radionuclides and can act as indicators allowing the detection and monitoring of radionuclides in an aqueous environment when radionuclide concentrations are otherwise undetectable. Large samples can be easily collected and ashed to small volumes, enabling very sensitive analyses.

5.4 Radionuclides in Fish

5.4.1 *Introduction.* Barnegat Bay is a popular sport and commercial fishing area. Fish caught from the bay are commonly sold to local fish markets and restaurants, while sport fishermen frequent the bay throughout the year. *(3)* Over fifty species of fish have been identified in the bay, although many are not eaten by man. *(9)* During the period 1960–1969, seven species of fish were taken commercially. *(3)* These species with the estimated total ten-year catch in kgs are given below.

Winter flounder	45,500	Mullet	34,100
White perch	14,800	Shad	400
Alewives	14,800	Black fish	200
Eels	136,000		

In 1969, however, only the first four species were taken commercially, totaling 34,700 kg valued at $215,000. The quantity of fish taken by sportsmen, including many more species than taken commercially, is not known but is undoubtedly quite large.

The life histories and distribution of most of the estuarine fish of Barnegat Bay are not well known. Their presence in the bay depends upon a number of factors, including spawning season, feeding habits and conditions existing in the estuary. *(23)* In this report, the fish have been classified according to feeding habits and human consumption, both being important in consideration of the food chain.

Estuarine fish are abundant in both the intake and discharge canals because of the circulation of bay water and the higher temperature of the discharge canal in winter. Fishermen are active along the banks of these canals throughout most of the year. The high water temperatures of the discharge canal result in some fish remaining long after they would normally have departed for warmer southern waters. Fish then become thermally trapped and cannot escape to the south through the cold water of Barnegat Bay. This perpetuates fishing in the discharge canal during the colder months of the year. *(24)*

5.4.2 Collection and analysis. On the initial field trips in September and October 1971, fish were collected from five sites in Barnegat Bay and from both canals. On trips in April, July and November of 1972, fish were collected from only three sites in Barnegat Bay and one in Great Bay.* These sites corresponded to those selected for sampling benthic algae, discussed in Section 5.3.1. Fish from Great Bay were considered control samples. All fish were collected by trawling. Sampling for fish in the discharge and intake canals was eliminated in 1972, due to the debris which fouled the trawl. A sample of menhaden *(Brevoortia tyrannus)* killed by thermal shock in the discharge canal was obtained in January 1972.

The 18 species of collected fish are listed in Table 5.12 with the number collected, feeding habits, habitat (environment – behavior), and edibility. Although menhaden are not generally eaten, they are processed into a protein concentrate which may be used to alleviate protein deficiency in some populations and into a meal for poultry and cattle. *(25)* Silversides are eaten only by some ethnic groups. The relative number of each fish species collected is similar to that found in a fish survey conducted during 1966–1968, except for the relatively large number of menhaden present in the discharge canal during winter. *(9)* Their presence in large numbers was undoubtedly due to the heated discharge, as menhaden were not captured in the bay during any of the field trips.

Samples were frozen immediately after collection and returned to the laboratory on dry ice. For analysis, the fish were thawed and weighed, and those of sufficient size were dissected into muscle, bone, gut, and kidney plus liver. Separation of muscle from the skeleton was facilitated by cooking in a microwave oven; however, some small bones, particularly in small fish, may have been retained in the muscle. *(26)* Small fish were analyzed whole. When sample size was sufficient, samples were combined for analysis by species of fish for each sampling site.

To measure volatile radionuclides, all soft tissues were analyzed in fresh form directly by gamma-ray spectrometry with a 10- x 10-cm NaI(Tl) detector and 54-cm^3 or 85-cm^3 Ge(Li) detectors. For higher ^{60}Co and ^{131}I sensitivities, samples of liver-kidney were also analyzed with a NaI(Tl) gamma-ray coincidence/anti-coincidence system. The iron fraction was separated and analyzed for ^{55}Fe with an x-ray proportional detector.

Bone was ashed at 600° C, and strontium was separated chemically. Radiostrontium was measured by counting total strontium and ^{90}Y. *(27)* Stable

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*We thank E. G. Karvelis, USEPA, for his assistance in collecting and identifying these samples and the Edison Water Quality Laboratory and the National Field Investigations Center-Cincinnati, USEPA, for making available boats and sample collecting apparatus.

Table 5.12 Fish Collected in Barnegat and Great Bays

Fish Name	No. Collected	Food	Habitat+	Human Consumption
Atlantic Menhaden (Brevoortia tyrannus)	100's	Plankton	Migrant	No
Atlantic Silversides (Menidia menidia)	1000's	Plankton	Resident	Yes
Blackfish or Tautog (Tautoga onitis)	20	Shellfish, crustacean	Migrant	Yes
Bluefish (Pomatomus saltatrix)	1	Fish	Migrant	Yes
Fourspine Stickleback (Apeltes quadracus)	1000's	Plankton	Resident	No
Jack (Caranx sp.)	9	Fish	Migrant	Yes
Northern Kingfish (Menticirrhus saxatilis)	7	Invertebrates*	Migrant	Yes
Northern Puffer (Sphaeroides maculatus)	11	Invertebrates	Migrant	Yes
Northern Searobin (Prionotus carolinus)	2	Opportunist**	Local marine	No
Oyster Toadfish (Opsanus tau)	50	Opportunist	Resident	Rarely
Shorthorn Sculpin (Myoxocephalus scorpius)	6	Opportunist	Resident	No
Silver Perch (Bairdiella chrysura)	225	Fish, invertebrates	Migrant	Yes
Striped Killifish (Fundulus majalis)	100's	Plankton	Resident	No
Summer Flounder (Paralichthys dentatus)	3	Fish, invertebrates	Small - resident Large - migrant	Yes
Weakfish (Cynoscion regalis)	1	Fish, invertebrates	Migrant	Yes
White Perch (Roccus americanus)	68	Fish, invertebrates	Resident	Yes
Windowpane (Scophthalmus aquosus)	7	Invertebrates	Local marine	Yes
Winter Flounder (Pseudopleuronectes americanus)	422	Invertebrates	Small - resident Large - migrant	Yes

* Bottom feeder
**Consumes any food available to him, including crustacean and shellfish.
+ Migrant - fish that enter the bay during certain seasons of the year either for spawning or for feeding in nursery grounds.
Resident - fish continuously present in the bay and which carry out their complete life cycle in the bay.
Local marine - indigenous fish that have their greatest abundance in shoreline waters, but are also common in estuarine waters.

strontium and calcium were determined by atomic absorption spectroscopy.

Muscle and gut were dried at 100°C, ashed at 400°C, and then analyzed by gamma-ray spectrometry. The potassium content of the muscle was calculated from the ^{40}K measurement (848 pCi ^{40}K/gm K) and stable calcium, strontium and iron concentrations were determined by an atomic absorption spectrometer. Radiochemical analyses were performed to measure ^{90}Sr. Analyses for ^{3}H and ^{14}C were made by treating 4-g aliquots of fresh sample in a combustion train, collecting water and CO_2, and measuring the radioactivity with a liquid scintillation counter. The minimum detectable concentrations at the 95 percent confidence level were 250 pCi ^{3}H/kg fresh weight and an excess of 6 dpm ^{14}C/g C above the normal background concentration.

5.4.3 *Results and discussion of stable element concentrations.* The concentrations of calcium, strontium, potassium and iron in whole fish or muscle and of calcium and strontium in bone are given in terms of fresh weight in Table 5.13. The ash weight/fresh weight ratios were measured and found to be constant between tissues of the same type. The mean weight ratios with standard deviations for individual samples were:

Fish muscle	0.016 ± 0.003 g ash/g fresh weight
Whole fish	0.036 ± 0.008 g ash/g fresh weight
Bone	0.17 ± 0.03 g ash/g fresh weight

These ratios may be applied to the data in Table 5.13 to convert concentrations to an ash weight basis. The collection site, date and the number of fish comprising each sample are also given.

Concentrations of strontium and calcium in fish bone were reasonably constant. The mean concentrations were 0.24 ± 0.03 g Sr/kg fresh weight and 49 ± 7 g Ca/kg fresh weight. The calcium concentration is similar to that observed previously in fresh water fish, but the strontium concentration is significantly higher *(26,28,29)*. The average ratio of Sr/Ca in bone is 4.9 ± 0.6 mg Sr/g Ca, very similar to that observed in muscle, 4.5 ± 0.6 mg Sr/g Ca. The high and variable concentrations of calcium and strontium in muscle reflects to a great degree contamination of muscle by bone, which yields a low bone/muscle concentration ratio. The highest bone/muscle ratio observed is about 90 (sample #10), which approaches the previously reported ratio of 100 *(26)* and is similar to that found by Templeton and Brown *(30)*. Assuming a concentration ratio of 100 for strontium and calcium in bone to bone-free muscle is probably reasonable. Dividing the average Sr/Ca ratio measured in the fish by the average Sr/Ca ratio measured in water, 19.9 mg Sr/g Ca (see Section 5.2.2), yields an O.R.* of 0.25. This value agrees with those previously reported and reflects a strong discrimination against strontium relative to calcium in fish bone *(26,29-31)*.

The mean concentrations of potassium and iron in fish muscle were 3.0 ± 0.5 and 0.027 ± 0.015 g/kg, respectively. These concentrations are in agreement with published concentrations for marine fish *(11)*.

Concentration factors (CF) for these elements in fish were calculated using the fish muscle concentrations listed in Table 5.13 and the corresponding water concentrations given in Table 5.1. As the concentration of iron in the water samples was below the minimum detectable level, the computed value of 0.04 mg Fe/liter (see Section 5.2.2) was used in these calculations. The average potassium concentration measured in the four July 1972 water samples, 200 ± 15 mg/liter, was assumed to be uniform with respect to time and was used to calculate the CF for potassium (see Section 5.2.2). Also, because of the contamination of muscle by bone, the concentration of strontium and calcium in the muscle (bone-free) is assumed to be 1 percent of that measured in bone, as discussed above. Concentration factors calculated for fish muscle from these data and those reported in the literature are:

Source	Sr	Ca	K	Fe
This study	0.45	1.8	15	700
Ref.* 12	0.3-0.6	1.4-2.3	—	—
Ref. 11	0.5	0.5	11	3000
Ref. 18	0.43	1.9	16	1800
Ref. 20	0.1	1.5	13	1600

*Reference

Concentration factors calculated from data of this study compare well with the referenced values, except for iron which is about 1/4 to 1/2 that usually cited. This low iron CF is probably due to an overestimated iron concentration in water. The CF listed for calcium in reference 11 appears low.

Normally the CF's for whole fish are unimportant because only the muscle is consumed by man.

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*O.R. (Observed Ratio) = $(\text{mg Sr/g Ca})_{bone} \div (\text{mg Sr/g Ca})_{water}$

Table 5.13 Concentration of Stable Elements in Fish, g/kg Fresh Weight

Sample No.	Fish type	Date collected	Collection site*	No. of fish	Muscle				Bone	
					Ca	Sr	K	Fe	Ca	Sr
1A	toad fish	9/23/71	B	4	1.71	0.0081	2.4	0.015	40	0.24
21	flounder	4/18/72	B	25	0.81	0.0038	2.5	0.034	36	0.19
28	mixture	7/12/72	B	27	5.03	0.010	5.6	0.022	45	0.21
39	jack, bluefish	11/1/72	B	11	1.35	0.0053	2.6	0.010	60	0.24
40	blackfish, toadfish	11/1/72	B	4	1.10	0.0044	3.4	0.011	66	0.31
16	flounder	10/19/71	G	18	1.24	0.0053	2.5	0.012	46	0.23
22	flounder	4/19/72	G	26	1.00	0.0047	3.1	0.050	55	0.26
29	flounder	7/12/72	G	28	2.02	0.0084	2.6	0.035	52	0.24
30	toadfish	7/12/72	G	4	1.68	0.0055	3.4	0.010	49	0.23
38	flounder	11/1/72	G	6	1.08	0.0052	3.8	0.012	54	0.24
20	flounder	4/18/72	H	15	0.67	0.0030	3.3	0.030	36	0.21
31	flounder	7/11/72	H	30	1.75	0.0067	1.4	0.050	44	0.22
11	flounder	10/18/71	D	26	1.60	0.0089	2.9	0.044	46	0.21
12	white perch	10/18/71	D	14	1.21	0.0054	3.2	0.027	52	0.30
17 (W)[†]	menhaden	1/30/72	D	many	5.1	0.020	2.1	0.084	---	---
23 (W)[†]	silversides	4/19/72	D	many	4.8	0.025	2.5	0.064	---	---
1	blackfish	10/21/71	I	1	0.82	0.0037	2.8	0.064	46	0.28
2	flounder	10/21/71	I	43	0.93	0.0045	2.1	0.012	38	0.19
15	flounder	10/19/71	I	28	1.00	0.0049	2.9	0.010	54	0.23
6	blackfish	10/20/71	I	8	1.22	0.0042	2.4	0.016	52	0.25
10	toadfish	10/20/71	I	9	0.57	0.0031	2.3	0.015	49	0.27
18	flounder	4/17/72	GB-X	24	0.68	0.0032	3.5	0.034	44	0.19
19	sculpin	4/17/72	GB-X	6	0.95	0.0056	2.9	0.034	54	0.29
24	flounder	7/10/72	GB-X	2	1.58	0.0073	3.0	0.062	58	0.23
35	white perch	10/31/72	GB-X	8	1.12	0.0060	3.5	0.012	59	0.26
36	flounder, windowpane	10/31/72	GB-X	5	1.10	0.0043	3.3	0.014	48	0.23

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*Letters refer to Figures 5.1 and 5.2.

[†] Whole fish.

However, menhaden and silversides are sometimes eaten whole (see Section 5.4.2). The CF's for these whole fish are

$$CF_{Ca} = 19 \qquad CF_{K} = 11$$
$$CF_{Sr} = 4 \qquad CF_{Fe} = 1850$$

The CF for potassium is the same as that in muscle, and the factors for calcium, strontium and iron are considerably higher in the case of whole fish.

5.4.4 *Results and discussion of radionuclide concentrations.* The results of the radionuclide analyses of whole fish and muscle, bone and gut are given in Tables 5.14 and 5.15. The concentrations are listed relative to fresh weight, but if desired, the ash weight/fresh weight ratios given in Section 5.4.3 may be applied to these data to convert concentrations to an ash weight basis. Gut was analyzed only in the fresh state.

The concentrations reported in fish generally agree with results from comparable samples analyzed by McCurdy *(6,7)*. The two predominant radioisotopes in these samples attributable to the station are ^{54}Mn and ^{60}Co. In addition to the radionuclides listed in Tables 5.14 and 5.15, ^{134}Cs was measured in 5 samples of whole fish or muscle and 2 samples of gut collected in the fall of 1972. These concentrations are listed in Table 5.16. All other samples of whole fish or muscle contained less than 20 pCi ^{134}Cs/kg. One fish muscle sample (No. 28) contained an excess of ^{14}C, 69 ± 5 dpm/g C, which was equivalent to 1670 ± 120 pCi/kg fresh weight. The mean ^{14}C concentration of all other fish muscle samples was 17.0 ± 2.5 dpm/g C (670 ± 100 pCi/kg fresh weight), the same as that recently reported for the normal specific activity of ^{14}C, 17 ± 2 dpm/g C *(22)*. No other radionuclides, including ^{58}Co, were detected in either muscle or gut. Also, no significant concentration of radionuclides was detected in any samples of kidney and liver, probably because of the small sample sizes.

The concentrations of ^{137}Cs in whole fish or muscle samples from Barnegat Bay, the discharge canal and the intake canal are similar to that in the Great Bay samples, except for five samples collected in November 1972 and one in October 1971. Omitting these six samples, the average ^{137}Cs concentrations and ^{137}Cs/K ratios were calculated for the four fish types, and the values are given in Table 5.17. The ^{137}Cs concentrations in fish from different sites were combined, as no significant difference between sites was observed. Except the predator, of which one sample from Great Bay was collected, the average values for fish from the environment of Oyster Creek are the same as those from Great Bay. The average ^{137}Cs concentration in all fish was 28 ± 10 pCi/kg fresh weight. This is much less than that reported for fresh water fish, but similar to that measured in shad collected in the Connecticut River estuary *(26,28,29)*. This is expected since CF's for fresh water fish are 10 to 100 times those for marine species *(11,12)*. Dividing the ^{137}Cs concentrations measured in whole fish or muscle by those measured in the water collected at the same time and site (see Table 5.3), results in an average CF for ^{137}Cs in fish of 50 ± 30. The values varied from 10 to 150, but the variation did not appear to correlate with feeding habits. Reported CF's are generally somewhat lower, 15-40 *(11,18-20)* but have been reported as high as 244 *(12)*.

The excess amounts of ^{137}Cs (concentration in fish less the concentration in that fish type from Great Bay) in the six fish samples which had concentrations significantly exceeding background levels were:

Sample No.	Fish type	Excess ^{137}Cs pCi/kg	^{134}Cs pCi/kg	^{134}Cs/^{137}Cs
		From Site B		
1A	Toadfish	37	ND*	—
39	Jackfish, Bluefish	120	79	0.66
40	Blackfish, Toadfish	96	55	0.57
41	Flounder	31	20	0.65
		From Site G		
37	Silver Perch	43	30	0.70
38	Flounder	44	28	0.64

*ND — not detected

The excess ^{137}Cs levels result from plant discharges. All fish were collected near the mouth of the discharge canal and, except for sample 1A, during a period (November 1972) of unusually high ^{134}Cs-^{137}Cs discharges (see Appendix B.4).

The ^{134}Cs/^{137}Cs ratios given in the above tabulation (background ^{137}Cs concentrations subtracted) approximate the ^{134}Cs/^{137}Cs ratio of 0.70 ± 0.05 in station effluents from July through October 1972 (see Appendix B.4). This confirms that recent station discharges are the major source of excess ^{137}Cs and ^{134}Cs rather than dissolution or uptake from sediment, which would reflect a lower ^{134}Cs/^{137}Cs ratio.

The ^{90}Sr concentrations measured in fish bone are listed in Table 5.14. Except for sample 1A, ^{90}Sr concentrations in fish bone samples from Barnegat Bay were not significantly different than those in fish from

Table 5.14 Radionuclide Concentrations in Fish Muscle or Whole Fish and Bone, pCi/kg Fresh Weight

Sample No.	Fish type	Date	No. of fish	Whole fish or muscle ^{54}Mn	^{60}Co	^{90}Sr	^{106}Ru	^{137}Cs	Bone ^{90}Sr
	Barnegat Bay near mouth of Oyster Creek (B)								
1A	Toadfish	9/23/71	4	34 ± 5	54 ± 7	1.5 ± 0.5	<30	75 ± 5	200 ± 50
21	Flounder	4/18/72	25	6 ± 2	<5	1.7 ± 0.6	<8	26 ± 3	33 ± 8
28	Silver perch Puffer Flounder Toadfish	7/12/72	10 <5 6 6	<5	15 ± 3	NA	27 ± 12	54 ± 4	46 ± 13
39	Jackfish Bluefish	11/1/72	9 2	<16	30 ± 13	1.2 ± [illegible]	[illegible]	170 ± 20	50 ± 15
40	Blackfish Toadfish	11/1/72	3 1	<7	26 ± 8	1.1 ± 0.4	NA	134 ± 9	76 ± 15
41	Flounder (Whole)	11/1/72	4	15	53 ± 8	2.1 ± 0.8	NA	60 ± 12	
	Barnegat Bay near mouth of Cedar Creek (C)								
16	Flounder	10/19/71	18	5 ± 2	<5	1.8 ± 0.6	<15	17 ± 2	36 ± 15
22	Flounder	4/19/72	26	<4	<4	2.4 ± 0.5	26 ± 8	30 ± 2	49 ± 17
29	Flounder	7/12/72	28	<8	<5	NA	<40	32 ± 4	34 ± 15
30	Toadfish	7/12/72	4	<7	<8	0.9 ± 0.4	NA	37 ± 6	64 ± 11
37	Silver perch (Whole)	11/1/72	50	7 ± 2	15 ± 2	2.8 ± 0.6	NA	93 ± 6	—
38	Flounder	11/1/72	6	<6	8 ± 3	0.5 ± 0.3	NA	71 ± 6	50 ± 12
	Barnegat Bay near Waretown (H)								
20	Flounder	4/18/72	15	10 ± 3	5 ± 1	0.5 ± 0.3	26 ± 8	33 ± 3	41 ± 8
31	Flounder	7/11/72	39	<6	6 ± 2	1.3 ± 0.5	29 ± 10	24 ± 3	50 ± 14
32	Toadfish (Whole)	7/11/72	6	8 ± 2	29 ± 4	11 ± 2	40 ± 14	41 ± 4	—
33	Silver perch (Whole) Blackfish (Whole)	7/11/72	4 3	<5	8 ± 3	NA	28 ± 10	17 ± 3	—
34	Puffer (Whole)	7/11/72	3	<15	<14	5 ± 1	<70	21 ± 8	—
	Oyster Creek (D)								
11	Flounder	10/18/71	26	<6	14 ± 4	1.0 ± 0.3	70 ± 20	18 ± 4	60 ± 15
12	White perch	10/18/71	14	12 ± 4	<8	1.4 ± 0.5	<30	28 ± 2	110 ± 25
13	Silver perch (Whole)	10/18/71	26	20 ± 3	21 ± 3	4.5 ± 1.0	35 ± 12	30 ± 3	—
17	Menhaden (Whole)	1/30/72	Many	29 ± 6	45 ± 5	6 ± 2	88 ± 13	17 ± 6	—
23	Silversides (Whole)	4/19/72	Many	6 ± 1	12 ± 3	3.6 ± 0.8	35 ± 10	25 ± 3	—
	South branch of Forked River (F)								
5	Toadfish (Whole)	10/21/71	4	7 ± 4	32 ± 7	35 ± 10	<40	33 ± 3	
1	Blackfish	10/21/71	1	<10	9	0.9 ± 0.6	<40	45 ± 10	60 ± 20
2	Flounder	10/21/71	43	<5	7 ± 2	2.5 ± 1.0	12 ± 4	14 ± 3	36 ± 14

Table 5.14 Radionuclide Concentrations in Fish Muscle or Whole Fish and Bone, pCi/kg Fresh Weight (Cont'd)

Sample No.	Fish type	Date	No. of fish	Whole fish or muscle					Bone
				^{54}Mn	^{60}Co	^{90}Sr	^{106}Ru	^{137}Cs	^{90}Sr
4	Silver perch (Whole)	10/21/71	75	<4	[illegible]	[illegible] ± 1	[illegible] ± 10	24 ± 4	
5	White perch (Whole)	10/21/71	6	<6	<6	10 ± 2	24 ± 13	8 ± 4	
	Barnegat Bay between Oyster Creek and Forked River (1)								
14	Silver perch (Whole)	10/19/71	35	15 ± 3	<6	10 ± 2	10 ± 10	34 ± 3	
15	Flounder	10/19/71	26	<4	<6	[illegible]	<20	24 ± 4	63 ± 13
	Barnegat Bay near Surf City (1)								
6	Blackfish	10/20/71	8	<7	<8	1.8 ± 0.6	<20	31 ± 6	41 ± 16
7	Flounder (Whole)	10/20/71	21	16 ± 3	<4	2.3 ± 1.0	40 ± 20	43 ± 6	
8	Puffer (Whole)	10/20/71	5	20 ± 6	<10	12 ± 3	<40	20 ± 6	
9	Silver perch (Whole)	10/20/71	14	<6	<8	[illegible] ± 1	40 ± 20	15 ± 3	
10	Toadfish	10/20/71	4	<7	<6	1.0 ± 0.4	<20	[illegible] ± 6	105 ± 30
	Barnegat Bay near Island Beach (1)								
2A	Toadfish (Whole)	9/23/71	4	21 ± 7	<3	[illegible] ± 2	<30	24 ± 8	
	Great Bay (control)								
18	Flounder	4/17/72	24	<3	<5	NA	[illegible]	25 ± 3	80 ± 16
19	Sculpin	4/17/72	6	<10	<5	NA	<10	44 ± 4	37 ± 19
24	Flounder	7/10/72	2	<7	<8	NA	<10	36 ± 3	45 ± 12
25	Toadfish (Whole)	7/10/72	2	<5	<6	[illegible]	<20	35 ± 4	
26	Blackfish (Whole) Searobin	7/10/72	3 2	<5	<5	[illegible] ± 1	<20	34 ± 4	
27	Silversides Stickelback (Whole) Killifish	7/10/72	Many	<3	<3	9 ± 2	30 ± 13	24 ± 2	
35	White perch	10/31/72	8	<6	<5	NA	24 ± 16	38 ± 5	75 ± 20
36	Flounder Windowpane	10/31/72	3	<6	<6	0.9 ± 0.4	NA	26 ± 10	42 ± 14

Notes:

1. Locations: See Figures 5.1 and 5.2 for sites B to I in Barnegat Bay and A in Great Bay.
2. < values are 3σ counting error; ± values are 2σ counting error.
3. Radionuclides below detectable quantities were ^{3}H (< 250), ^{7}Be (< 35), ^{32}P (< 200), ^{51}Cr (< 25), ^{55}Fe (< 80); ^{59}Fe (< 30); ^{58}Co (< 10); ^{65}Zn (< 25); ^{95}Zr–^{95}Nb (< 10), ^{131}I (< 20), ^{134}Cs (< 20), ^{141}Ce (< 30), ^{144}Ce (< 15); all values in pCi/kg fresh weight.
4. Sample No. 28 contained 69 ± 5 dpm $^{14}C/gC$. The mean concentration of all other samples was [illegible] dpm $^{14}C/gC$.

Table 5.15 Radionuclide Concentration in Fish Gut, pCi/kg Fresh Weight

Sample No.	Fish type	^{54}Mn	^{60}Co	^{106}Ru	^{137}Cs
1A	Toadfish	36 ± 12	81 ± 19	90 ± 50	40 ± 11
1	Blackfish	100 ± 34	54 ± 27	< 140	< 45
2	Flounder	61 ± 25	92 ± 10	180 ± 50	16 ± 7
6	Blackfish	< 30	< 25	< 110	< 90
10	Toadfish	58 ± 21	< 13	45 ± 30	65 ± 7
11	Flounder	184 ± 32	510 ± 35	500 ± 120	< 40
12	White Perch	81 ± 27	280 ± 40	185 ± 100	210 ± 30
15	Flounder	< 23	80 ± 20	< 180	120 ± 15
16	Flounder	39 ± 11	40 ± 20	< 150	90 ± 15
18	Flounder	< 25	< 25	< 160	< 30
19	Sculpin	< 10	< 10	< 50	30 ± 10
20	Flounder	50 ± 7	35 ± 16	< 160	100 ± 10
21	Flounder	70 ± 30	100 ± 25	NA	< 30
22	Flounder	38 ± 6	40 ± 7	< 45	50 ± 6
28	Mixed	< 20	70 ± 20	< 150	60 ± 15
29	Flounder	< 35	< 30	< 110	55 ± 30
30	Toadfish	< 35	60 ± 25	< 110	110 ± 30
31	Flounder	< 20	64 ± 22	< 150	65 ± 15
35	White Perch	< 40	< 40	< 150	< 75
36	Flounder Windowpane	< 35	< 30	< 150	< 45
38	Flounder	< 100	130 ± 40	< 200	< 140
39	Jackfish Bluefish	< 70	100 ± 40	< 300	300 ± 75
40	Blackfish Toadfish	90 ± 40	500 ± 60	500 ± 200	160 ± 40

Notes:

1. < values are 3σ and ± values are 2σ counting error; radionuclides below detectable quantities were : ^{65}Zn (< 90 pCi/kg) and ^{134}Cs (< 50 pCi/kg).
2. ^{134}Cs was measured in two samples: #39 (110 ± 40); #40 (65 ± 25).

Table 5.16 Concentration of ^{137}Cs in Fish Samples

Sample No.	Fish type	Site**	Muscle pCi/kg+	Gut pCi/kg+
37	Silver Perch*	[illegible]	[illegible]	
38	Flounder	[illegible]	[illegible]	[illegible]
39	Jackfish, Blowfish	B	[illegible]	[illegible]
40	Blackfish, Goatfish	B	[illegible]	[illegible]
41	Flounder*	B	[illegible]	

* Whole fish

** Letters refer to Figure [illegible]

+ Concentrations based on fresh weight

Table 5.17 Average ^{137}Cs Concentration in Uncontaminated Fish

	Station Environment		Great Bay	
Fish type	pCi/kg*	pCi/g*	pCi/kg*	pCi/g*
Planktonic	[illegible]	[illegible]	[illegible]**	[illegible]
Bottom feeders	[illegible]	[illegible]	[illegible]	[illegible]
Opportunists	[illegible]	[illegible]	[illegible]	[illegible]
Predator	[illegible]	[illegible]	[illegible]**	[illegible]

* Fresh weight

** Only one sample collected

Uncertainties are the standard deviations of the individual measurements

Great Bay. The bones of sample 1A, 4 toadfish collected in September 1971, contained about 4 times the ^{90}Sr as the bones of fish from Great Bay. The average ^{90}Sr concentration of all other fish bone samples was 57 ± 20 pCi/kg fresh weight, 0.23 ± 0.05 pCi/mg Sr and 1.1 ± 0.3 pCi/g Ca. Similar to the stable strontium results discussed above, the concentrations are much less than those usually observed in fresh water fish.*(26,28,29)* Taking the water concentrations of calcium and ^{90}Sr from Tables 5.1 and 5.3, respectively, the average OR is 0.7 ± 0.4. This OR is much higher than that calculated for stable strontium (see Section 5.4.3) and that normally observed for ^{90}Sr, 0.1-0.7.*(30,31)* Because of the high OR variability between samples, as reflected in the large standard deviation and the large uncertainty associated with ^{90}Sr measurements in water (see Table 5.3), it is recommended that the OR calculated for stable strontium in Section 5.4.3 be applied to ^{90}Sr. No ^{89}Sr was detected in any fish bone samples at the minimum detectable concentration of 60 pCi/kg fresh weight (3σ counting error).

Both ^{60}Co and ^{54}Mn were in fish gut at higher concentrations than in muscle. In the 8 samples of whole fish or muscle which contained measurable amounts of both ^{54}Mn and ^{60}Co, the average activity ratio of ^{60}Co/^{54}Mn is 2.1 ± 1.3. This is very similar to the ratio in fish gut and in the effluent discharged during this period, 2.4 ± 0.6 (see Appendix B.4). These ratios, however, appear inconsistent with published CF's for these two nuclides, 600 for ^{54}Mn and 100 for ^{60}Co.*(11)* Based on the ^{60}Co/^{54}Mn activity ratio of 2.4 in station effluent, the activity ratio in fish muscle according to these CF's should be about 0.4, if both radionuclides are in a chemical form equally available for uptake. Since the fractions of ^{60}Co and ^{54}Mn in soluble form in canal water were found to be similar (see Section 4.4.4), it is assumed that differences in chemical availability would not account for this large difference. Hence, either the CF's for these two radionuclides are about the same for these fish, or ^{60}Co from another source is available. Since much of the food for most of these fish is obtained either directly or indirectly from the bottom, such a source may be the benthos which is associated with sediments containing about 6 times more ^{60}Co that ^{54}Mn (see Section 5.7.4). If the latter is true, estimated concentrations in fish based on water to fish CF's will be in error.

The ^{60}Co concentration in fish collected at the mouth of the discharge canal (Site B) during the four field trips increased with the total ^{60}Co discharged during a 2-month period immediately preceding collection. The increase in fish muscle concentration, however, was not proportional to the amounts discharged. Variable and unknown factors contributing to this are:

1) The existence of varying fractions of soluble and insoluble (particulate) radionuclides in the waste solution discharged by the station. The ^{60}Co and ^{54}Mn in soluble form ranged from about 1 to 50 percent (see Section 4.4.4). Hence, the total amount discharged is not a measure of the quantity of radionuclides available to fish if only the soluble fraction is available for uptake.*(32)*
2) The time fish remain in contaminated water as well as the time during which the discharge occurs and the interval between discharges.
3) The uptake of radionuclides by fish from sources other than the water.*(32)* For predator fish and those that eat shellfish and benthic organisms, the major source is probably their food. For example, the muscle of the toadfish (sample 1A) which contained a large number of gastropods in its gut had high concentrations of both ^{60}Co and ^{54}Mn even though the plant had discharged less than 0.07 Ci of either for 9 months before sample collection. Rice has shown that fish obtain

more than twice as much ^{65}Zn from food than from water when both contain the same concentration,*(33)* and the uptake of ^{54}Mn and ^{60}Co may be of a similar nature.

4) Due to the complex hydrology, it is not possible to ascertain dilution factors for various sites in the bay.

The effects of these factors, and possibly others, are reflected in the results of the menhaden samples collected on January 30, 1972. Movement of these fish probably had been restricted to the discharge canal for 3 months because of the low water temperature of the bay. Based on station effluent data and the available dilution in Oyster Creek, the average water concentrations of ^{54}Mn and ^{60}Co for the 3-month period, November 1971 through January 1972, were 1.32 and 2.55 pCi/liter, respectively (see Appendix B.4). Dividing these concentrations into those measured in the fish yield CF's for ^{54}Mn and ^{60}Co of only 22 and 18, respectively. The principal reasons for these very low estimated CF's are probably items 1 and 2 above.

5.4.5 *Hypothetical radionuclide concentrations in fish.* Radionuclide concentrations in fish exposed to radioactive effluents in the discharge canal from the station are computed in Table 5.18 to indicate possible critical radionuclides.

These calculated hypothetical concentrations are based on CF's for edible portions of marine fish,*(11,15,34-36)* the estimated annual average 1971-1973 concentrations of radionuclides in the discharge canal water (see Section 5.2.4) and the assumption that radionuclides in the edible portions of all consumed fish had reached equilibrium with concentrations in canal water. Of these factors and assumptions, the calculated water concentrations and many of the CF's are quite approximate, and it is highly improbable that radioactive equilibrium in fish is attained. Also, the first three factors discussed in Section 5.4.4 will apply to these calculations, increasing the uncertainty of these estimated concentrations.*(33)*

The hypothetical ^{134}Cs and ^{137}Cs concentrations in fish agree with average measured concentrations of ^{134}Cs and excess (above background) ^{137}Cs in fish at sites B and D. This would indicate that a CF of 30 for cesium is reasonable. The calculated values for ^{54}Mn and ^{60}Co are much higher than any measured concentrations in fish from these two sites. The hypothetical concentrations for ^{55}Fe, ^{59}Fe and ^{65}Zn are significantly higher than the minimum detectable levels determined for fish muscle, and would have been detected if present at these concentration levels. The absence of equilibrium conditions and dilution of the canal water as it enters the bay at Site B contribute significantly to these differences. Also, these radionuclides are activation products released to the coolant by corrosion. Therefore, all might be associated with particulate matter and unavailable for uptake by fish.

The values in the last column of Table 5.18 are based on an assumed average daily consumption of 50 g of fish.*(37)* The calculations assume the maximum permissible daily occupational drinking-water intake listed by the International Commission on Radiation Protection (ICRP) to correspond to 5 rem/yr to the total body, 15 rem/yr to the GI tract, and 30 rem/yr to bone.*(38,39)* These values, listed in Appendix F.2 for each radionuclide, assume the daily intake persists for either 50 years or until equilibrium is reached in the body. The limits given for the radioiodines are based on a child's thyroid.

Phosphorus-32 appears to be the critical radionuclide discharged by the station. The annual dose rates from the listed radionuclides would be 5.7 mrem/yr to bone (mostly from ^{32}P), 1.1 mrem/yr to a child's thyroid (mostly from ^{131}I), 0.9 mrem/yr to the GI tract (mostly from ^{32}P), and 0.3 mrem/yr internal whole body (mostly from ^{32}P). Except to the thyroid, ^{32}P contributes the major dose to the other organs of the body, and for this reason, the doses calculated here exceed those estimated by the U.S. Atomic Energy Commission (USAEC) whose calculations did not include ^{32}P.*(3)* Fish collected on October 31, 1973, were analyzed for ^{32}P but it was not measurable above the minimum detectable concentration of 200 pCi/kg, equivalent to a dose to the bone of $<$ 0.7 mrem/yr. However, this result is not certain because the amount of ^{32}P last discharged is not known. Sensitive measurement of both ^{32}P and ^{131}I in fish is recommended for future studies.

Radiation doses based on measured radionuclide concentrations in muscle are much lower than those estimated from hypothetical concentrations. The average measured muscle concentrations for fish collected from Oyster Creek (D) and near its mouth (B) and of ^{90}Sr inferred from fish bone analyses are listed in the second column of Table 5.19 relative to a 50 g sample. This average includes 111 fish combined into 7 samples collected during four periods of the year. Subtracting the concentrations in muscle of fish collected from Great Bay gives the amount in the canal fish due to the station. These values are listed in the third column. Listed in the next column are the annual radiation exposures due to station operation based on a daily fish intake of 50 g and the dose rate-daily intake relationships given in Appendix F.2. According to

Table 5.18 Hypothetical Radionuclide Concentrations in Fish from Oyster Creek

Radionuclide	Annual average concentration in canal water, 1971-1973,* pCi/l	Concentration factor**		Hypothetical concentration in canal fish,† pCi/kg	Percent of limit††
^{3}H	34.6	0.93	(11)	32	<0.001 TB
^{14}C	0.0075	1800	(11)	13	<0.001 TB
^{32}P	0.056	30000	(11,20)	1680	1 B 0.12 TB 0.37 GI
^{51}Cr	0.22	100	(34)	22	<0.001 GI
^{54}Mn	0.35	600	(11)	210	0.04 GI
^{55}Fe	0.49	1600	(20)	780	0.02 S
^{59}Fe	0.026	1600	(20)	42	0.01 GI
^{58}Co	0.085	100	(11)	8.5	0.002 GI
^{60}Co	0.76	100	(11)	76	0.03 GI
^{64}Cu	0.077	670	(11)	52	0.001 GI
^{65}Zn	0.015	2000	(11)	30	0.002 TB
^{76}As	0.11	330	(11)	36	0.04 GI
^{89}Sr	0.22	0.5	(11)	0.11	0.001 B
^{90}Sr	0.030	0.5	(11)	0.015	0.001 B
^{91}Sr	0.034	0.5	(11)	0.017	0.001 GI
^{95}Zr	0.013	30	(34)	0.39	0.001 GI
^{95}Nb	0.021	100	(20)	2.1	0.001 GI
^{99}Mo	0.16	10	(11,20)	1.6	0.001 GI
^{99m}Tc	0.16	10	(11)	1.6	0.001 GI
^{103}Ru	0.0078	3	(34)	0.023	0.001 GI
^{105}Rh	0.11	10	(11)	1.1	0.001 GI
^{110m}Ag	0.0064	1000	(34)	6.4	0.004 GI
^{124}Sb	0.002	40	(11)	0.080	0.001 GI
^{131}I	0.27	10	(11)	2.7	0.17 T
^{133}I	0.22	10	(11)	2.2	0.01 T
^{134}Cs	0.54	30	(11)	16	0.01 TB
^{137}Cs	0.82	30	(11)	25	0.008 TB
^{140}Ba	0.11	10	(11)	1.1	0.001 GI
^{141}Ce	0.032	25	(11)	0.80	0.001 GI
^{144}Ce	0.020	25	(11)	0.50	0.001 GI
^{239}Np	0.44	10	(11)	4.4	0.001 GI

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* From Section 5.2.4; for 1971 and 1972, ^{89}Sr and ^{90}Sr assumed to be in same ratio as in 1973.

** References given in parentheses.

† The product of the values in columns 2 and 3.

†† The limit is based on an intake of 50 g fish per day that will result in an exposure equal to the Radiation Protection Guides recommended by the FRC[40]; the RPG are 500 mrem/yr for thyroid (T) and bone (B), and 170 mrem/yr for all other critical organs, total body (TB), gastrointestinal tract (GI), and spleen (S).

Table 5.19 Radiation Dose from Eating Fish

Radio-nuclide	Average concentration measured in fish, pCi/50 g*		Radiation dose from station, mrem/yr	Critical organ
	total	from station		
^{14}C	10	6	0.0014	Whole Body
^{54}Mn	0.50	0.50	0.0033	GI(LLI)
^{60}Co	1.04	1.04	0.015	GI(LLI)
^{90}Sr	0.012†	0.014	0.04	Bone
^{106}Ru	1.17	0.06	0.004	GI(LLI)
^{134}Cs	1.2	1.2**	0.030	Whole Body
^{137}Cs	3.61	1.80	0.020	Whole Body

* Average concentration measured in fish muscle collected from Oyster Creek (D) and at its mouth (B); < values averaged as 1/2 the < value.

** Based on a $^{134}Cs/^{137}Cs$ ratio of 0.64 (see Section 5.4.4).

† Based on a bone/muscle ratio of 100 (see Section 5.4.5).

measured concentrations, a person consuming 50 g of fish per day will receive a radiation dose due to station operation of about 0.05 mrem/yr to the whole body, 0.02 mrem/yr to the GI tract, and 0.04 mrem/yr to the bone from ^{90}Sr. These dose rates are small, less than 0.1 percent of the recommended FRC limit to the whole body or any critical organ *(40)*.

In the case of menhaden for fish protein concentrate (FPC) to supplement diets,*(41)* sample no. 17 should reflect the radiation dose received by consumers as a result of station discharges. Menhaden, collected on January 30, 1972, had been in the discharge canal for probably at least 3 months.*(42)* About 3 kg of fresh fish yields 0.45 kg of FPC.*(25)* Since about 10 g of FPC per day is needed to alleviate the effects of protein deficiency, an equivalent daily intake of 66 g of fresh fish is required. Assuming no loss of radionuclides during processing (an enzymatic digestion and an alcohol fat extraction) and a six-month decay period during processing and distribution, FPC consumers will receive about 0.25 mrem/yr to the GI(LLI), < 0.1 mrem/yr to the whole body and < 0.3 mrem/yr to the bone due to station discharge (concentrations in whole fish from Great Bay subtracted from concentrations measured in menhaden – Table 5.14). This is less than 0.2 percent of the FRC radiation protection guide.

5.5 Radionuclides in Shellfish

5.5.1 *Introduction.* Five species of shellfish have been of sport and commercial importance in the bay: hard clams (*Mercenaria mercenaria*), soft shelled clams (*Mya arenaria*), bay scallops (*Aequipectera irradians*), blue mussels (*Mytelus edulis*), and oysters (*Crassostrea virginica*). The shellfish catch for 1969, however, included no mussels or scallops, and much smaller amounts of soft shelled clams and oysters.*(3)* During this study from 1971 to 1973, only hard clams were taken commercially, and no evidence of any other shellfish species was observed although there were large masses of oyster shell debris. The catch of hard clams has remained fairly constant over the past 10 years despite the increased number of areas closed because of domestic sewage pollution.*(3)* In 1970, an estimated 419,000 pounds of meat from the hard clam was harvested and sold to markets and restaurants as far distant as New York City. *M. mercenaria* meat is prepared for consumption either as fresh clams on the half-shell or as chowder.

The mechanisms of trace element concentration in shellfish is not totally understood. Being "filter feeders," clams probably concentrate trace elements to a large degree through ingestion [illegible] particulate material from the water [illegible] trace metals concentrated in algae, plankton or other food material.*(43,44)* The complicated nature of this process is demonstrated by "filter-feeding" animals of different species living in the same environment and having the capacity to concentrate different radionuclides.*(33)* Because of their feeding habits and metabolic requirements, clams tend to concentrate a number of trace elements that are major radioactive corrosion products (Co, Mn, Cr, Zn, etc.) discharged in liquid effluents from nuclear power stations.*(33,43–45)* Because of this as well as the immobility of clams within beds located near the mouth of the discharge canal and the large quantities of clam meat from Barnegat Bay that are consumed by man, one might expect clams to concentrate certain radionuclides to higher levels than the mobile finfish, constitute a significant radiation exposure pathway to man, and be a good biological indicator of radionuclides in the aquatic environment.

5.5.2 *Collection and analysis.* Samples of *M. mercenaria* were collected from sites B, G and H in Barnegat Bay (see Figure 5.1). Samples were collected 5 times during the period of October 1971 to October 1973, although all sites were not sampled on each occasion. Background samples were also taken from Great Bay each time. The clams were collected in 1 to 3 meters of water by a clam rake operated from a boat. In addition to *M. mercenaria*, the large clam-eating whelk, *Busycon canaliculatum*, was obtained from Site H in April 1972 and from Site G in November 1972. Although this species is not normally eaten by man, it sometimes feeds on the *M. mercenaria* and, therefore, may contain higher levels of radioactivity.*(42)* One sample of the common mud snail, *Nassarius absoletus*, was taken from the gut of a large toadfish collected in September 1971 near the mouth of the discharge canal.

Rock barnacles *(arthropoda)* and polychaeta tubes were collected on two occasions. The former was obtained once beneath the route U.S. 9 bridge in the intake canal and twice beneath the railroad bridge in the discharge canl, while the latter was obtained twice at the intake canal sampling point. A large sample of annelid tubes from a live colony (species unknown) were obtained in the trawl at Site H near Waretown in April 1972.

Except for the last two samples, numbers 17 and 18, the shellfish were frozen in their shells and returned to the laboratory on dry ice. In the case of the last two samples, the clams were shucked in the boat as they were collected, and the meat and fluid were placed in separate containers and returned to the laboratory on ice.

The clam meat was thawed, removed from the shell, and analyzed for gamma-ray emitters and for ^{3}H, ^{14}C and radiostrontium as described in Section 5.4.2. The fluid of the *M. mercenaria* was analyzed separately. The shells were analyzed after removing all organic material. The snails, *N. absoletus*, were analyzed whole, as were the barnacles and the worm tubes after cleaning all foreign material from their exterior.

Samples of clam meat and fluid were analyzed for ^{210}Pb-^{210}Po by digesting the sample in HNO_3 and 72 percent $HClO_4$ at 85° C. The ^{210}Pb concentrations were calculated from the ^{210}Po ingrowth which was measured by repeating the ^{210}Po deposition on another silver disc 3 to 4 months after the initial deposition. The activity of the deposited ^{210}Po was measured in a low-background ZnS(Ag) scintillation counter. The measured ^{210}Po concentrations were corrected for ingrowth and decay to the time of collection.

5.5.3 *Results and discussion.* The shellfish collection data and analytical results are shown in Tables 5.20 and 5.21. The samples are listed in Table 5.20 according to the collection site. Sample sizes of *M. mercenaria* varied from 34 to 55 clams each, which were combined and homogenized prior to analysis. Only one *B. canaliculatum* consisting of about 130 g of meat was collected on each occasion.

Except in one case, the only radionuclides attributable to the station in the shellfish samples were ^{60}Co in the meat and fluid, which was detected in all samples except the controls from Great Bay and one of the large whelks, and ^{90}Sr in the shells. The one exception was *N. absoletus* obtained from the gut of a toadfish. These small gastropods contained relatively high levels of both ^{60}Co and ^{54}Mn. The consequence of this diet was reflected in an unusually high ^{60}Co and ^{54}Mn content in fish muscle (see Section 5.4.4, sample 1A in Table 5.14). This was the only shellfish sample in which ^{54}Mn was detected. The concentration of ^{60}Co in the clam meat did not vary significantly with time or location, and the mean concentration of all samples of clam meat from Barnegat Bay was 190 ± 40 pCi/kg fresh weight. This concentration is similar to that reported by McCurdy, who also did not detect ^{54}Mn in clams collected in 1972. Detectable amounts of ^{54}Mn, however, were reported in clams during 1971 (see Section 5.1.4).*(6)* This may indicate that higher levels of ^{54}Mn were discharged by the station in 1971 or earlier. Carbon-14 was detected in all samples near the normal level of 17 ± 2 dpm/g C.*(22)* The mean ^{14}C concentration measured was 18 ± 3 dpm/g C, which was equivalent to 270 ± 50 pCi/kg fresh weight.

Table 5.20 Radionuclide Concentrations in Shellfish, pCi/kg Fresh Weight

Sample No.	Species	Date	Number in Sample	Sample	^{60}Co	^{90}Sr	K**
			Bay, at mouth of Oyster Creek (B)*				
2	*M. mercenaria*	10/22/71	38	meat	200 ± 30	< 15	0.43 ± 0.05
				fluid	180 ± 20	NA	0.36 ± 0.08
				shell	20 ± 10	180 ± 50	0.20 ± 0.10
1A	*N. absoletus*[+]	9/23/71	8	whole	1300 ± 180	NA	4 ± 2
5	*M. mercenaria*	4/18/72	34	meat	170 ± 20	< 12	1.20 ± 0.10
				fluid	170 ± 25	NA	0.80 ± 0.20
				shell	17 ± 11	160 ± 50	0.40 ± 0.10
11	*M. mercenaria*	7/12/72	37	meat	230 ± 20	< 20	0.88 ± 0.09
				fluid	230 ± 30	NA	1.20 ± 0.20
				shell	40 ± 20	400 ± 40	0.40 ± 0.10
13	*M. mercenaria*	11/2/72	37	meat	180 ± 20	NA	0.70 ± 0.20
				fluid	160 ± 20	NA	0.90 ± 0.20
				shell	26 ± 11	120 ± 40	0.20 ± 0.10
18	*M. mercenaria*	10/31/73	50	meat	150 ± 10	NA	1.7 ± 0.2
				fluid	170 ± 15	NA	0.47 ± 0.09
				shell	33 ± 9	NA	0.25 ± 0.07
			Bay, off Waretown (H)				
1	*M. mercenaria*	10/22/71	41	meat	260 ± 50	< 20	1.50 ± 0.20
				fluid	230 ± 30	NA	0.46 ± 0.05
				shell	15 ± 9	95 ± 30	0.30 ± 0.10
7	*B. canaliculatum*	4/18/72	1	meat	< 25	NA	1.50 ± 0.20
				shell	NA	190 ± 50	NA
10	*M. mercenaria*	7/11/72	55	meat	150 ± 20	< 15	1.04 ± 0.10
				fluid	120 ± 20	NA	1.10 ± 0.10
				shell	35 ± 20	210 ± 40	0.26 ± 0.07

Table 5.20 Radionuclide Concentrations in Shellfish, pCi/kg Fresh Weight (Cont'd)

Sample No.	Species	Date	Number in Sample	Sample	^{60}Co	^{90}Sr	K**
14	*M. mercenaria*	11/2/72	45	meat	170 ± 20	NA	1.10 ± 0.20
				fluid	150 ± 30	NA	1.40 ± 0.50
				shell	30 ± 10	100 ± 50	0.14 ± 0.07
Bay, near mouth of Cedar Creek (G)							
15	*M. mercenaria*	11/2/72	45	meat	200 ± 30	< 20	1.16 ± 0.09
				fluid	190 ± 40	NA	1.60 ± 0.50
				shell	22 ± 9	220 ± 50	0.30 ± 0.10
16	*B. canaliculatum*	11/2/72	1	meat	160 ± 20	< 20	1.70 ± 0.20
				shell	NA	260 ± 50	NA
Great Bay (X)							
4	*M. mercenaria*†	4/17/72	36	meat	< 12	< 15	1.40 ± 0.10
				fluid	< 15	NA	1.10 ± 0.10
				shell	NA	90 ± 40	NA
9	*M. mercenaria*	7/10/72	55	meat	< 20	NA	1.30 ± 0.10
				fluid	< 20	NA	1.10 ± 0.20
				shell	< 17	120 ± 40	0.20 ± 0.10
12	*M. mercenaria*	10/31/72	37	meat	< 17	< 18	1.50 ± 0.30
				fluid	< 17	NA	1.10 ± 0.20
				shell	NA	110 ± 40	NA
17	*M. mercenaria*	10/30/73	40	meat	< 10	NA	1.30 ± 0.20
				fluid	< 10	NA	0.60 ± 0.10
				shell	< 11	NA	0.20 ± 0.10

* Locations: See Figures 5.1 and 5.2.

** Potassium given in units of g/kg, and based on there being 848 pCi ^{40}K/gK.

† Additional radionuclides were 3100 ± 200 pCi ^{54}Mn/kg in sample 1A, 40 ± 10 pCi ^{137}Cs/kg in sample 4, and a mean concentration of 18 ± 3 dpm ^{14}C/gC for all samples.

NA - Not analyzed.

Radionuclides below detectable quantities were ^{3}H (<250), ^{32}P (<400), ^{51}Cr (<250), ^{54}Mn (<20), ^{55}Fe (<100), ^{58}Co (<30), ^{65}Zn (<60), ^{95}Zr-^{95}Nb (<80), ^{131}I (<15), ^{134}Cs (<30), ^{137}Cs (<20); all values in pCi/kg fresh weight.

Table 5.21 The Concentration of ^{210}Pb and ^{210}Po in Shellfish Samples

Sample No.	Collection site*	Sample type	^{210}Po, pCi/kg	^{210}Pb, pCi/kg
12	GB-X	Meat	350 ± 5	70 ± 2
13	B	Meat	390 ± 10	70 ± 5
		Fluid	80 ± 3	15 ± 2
14	H	Meat	500 ± 10	30 ± 3
		Fluid	130 ± 8	10 ± 3
15	G	Meat	390 ± 5	70 ± 2
		Fluid	100 ± 2	15 ± 2
16	G	Meat	230 ± 10	20 ± 2

*Letters refer to map in Figure 5.2.

Notes:

1. All samples *M. mercenaria*, except No. 16 which is *B. canaliculatum*, and were collected between 10/31-11/2/72.
2. Errors are 2σ of the count rate.

The concentration of ^{60}Co was reported earlier to be higher in clam fluid than in meat.*(6)* The results in Table 5.20, however, show no significant difference in ^{60}Co concentration between the two media. The mean concentration of all samples of the clam fluid is 180 ± 30 pCi/kg. This level in clam fluid, similar to that in meat, is unexpected since a large portion of the fluid consists of sea water. It has been suggested that the ^{60}Co is associated with coarse particles that were rejected by the clam and became suspended in the fluid.*(6)* Another explanation may be that while the animals remain alive between collection and analysis, an equilibrium between meat and fluid is established. To test these hypotheses, the shellfish that were obtained in Barnegat Bay at the mouth of the discharge canal on October 31, 1973, were shucked in the boat immediately after collection and the meat and fluid were placed in separate containers, cooled on ice and returned to the laboratory for analysis. The results of the sample (No. 18, Table 5.20) again reflect similar concentrations of ^{60}Co in meat and fluid. After the initial fluid analysis, 400 cc were centrifuged at 2800 rpm for 30 minutes to remove particulate matter. The residue obtained contained less than 2 percent of the total ^{60}Co activity in the 400 cc sample. The protein fraction of the fluid was then separated by ultracentrifugation at 178,000 G's for 1 hour.* The protein recovered weighed 15 g wet and 2.75 g dry. The ^{60}Co activity associated with the protein fraction based on 400 cc was equivalent to 200 ± 12 pCi/1, while the concentration of the supernatant liquor was < 7 pCi/1. The ^{60}Co concentration based on that measured in the protein is in reasonable agreement with the original clam fluid measurement, 170 ± 15 pCi/1. These results indicate that ^{60}Co in clam fluid is associated closely with the protein and has been metabolized by the clam. This is important since clam fluid is often consumed with the meat.

The protein associated radioactivity may also explain the higher fluid concentrations relative to that of the meat reported earlier by McCurdy,*(6)* who recently observed that fluid samples separate into two phases upon prolonged standing.*(46)* The denser protein fraction, containing most of the radioactivity, settles nearer the container bottom (nearer the detector) leading to a better counting geometry than that when the radioactivity is uniformly distributed throughout the total sample volume. Because of this, fluid samples should be analyzed immediately after sample preparation to assure homogeneity.

The ^{60}Co concentrations in the two large whelk samples were considerably less than that measured in the *M. mercenaria*. This may be due to the filter feeding characteristics of the latter and the presence of ^{60}Co in the plankton and algae they consume. No ^{60}Co was detected in the sample collected in Barnegat Bay near Waretown (< 25 pCi/kg) and only 60 pCi/kg was measured in the sample from the site near Cedar Creek. This is only 30 percent of that in the *M. mercenaria* collected at the same site and time. Either this large whelk, which sometimes feed on *M. mercenaria*, as well as other invertebrates in the bottom sediments, had not done so recently or absorbed very little cobalt through the gut. Large differences in the ability of different species of mollusks to concentrate trace metals have been demonstrated.*(33)*

In most cases, the ^{90}Sr concentration in mollusk shells collected from the three Barnegat Bay sites were significantly higher than that in the controls from Great Bay. There were considerable variations in concentration between samples, and the concentrations in shells from the sites near Oyster Creek and Cedar Creek appeared higher than in those near Waretown. Concentrations of ^{90}Sr in the shells of *M. mercenaria* and *B. canaliculatum* were similar. The mean concentration of ^{90}Sr in all *M. mercenaria* shells from Barnegat Bay was 190 ± 100 pCi/kg, compared to 105 ± 15 pCi/kg in the shells from Great Bay. Subtracting the concentration of ^{90}Sr in the control shells of Great Bay from the concentration in the Barnegat Bay shells gives an average ^{90}Sr excess of 85 ± 100 pCi/kg. The ratio of strontium in shell to that in muscle is reported to vary from about 10 to 16.*(12,15,45,47)* Applying these ratios, the ^{90}Sr concentration in clam meat taken from these areas of Barnegat Bay would vary from about 10 to 25 pCi/kg, near or below the minimum detectable level of 20 pCi/kg.

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*We thank Dr. G. Murthy, USFDA, Cincinnati, Ohio, for assisting with the protein separation.

The average potassium concentration in muscle of *M. mercenaria* is 1.3 ± 0.4 g/kg, somewhat higher than that in the fluid, 1.0 ± 0.3 g/kg. Dividing the concentration in muscle by a CF of 6.6,*(11)* indicates a water concentration of 200 ± 60 mg/l, which agrees with the potassium concentration in water collected from Barnegat Bay (see Section 5.2.2).

No ^{3}H, ^{32}P, ^{60}Co or ^{65}Zn was detected in any shellfish. Manganese-54 was not detected in any samples of *M. mercenaria* or *B. canaliculatum*, and the ^{137}Cs concentration was below the minimum detectable level in all samples except #4 from Great Bay which contained 40 ± 10 pCi/kg. Radionuclides detected in the control samples from Great Bay were ^{40}K in meat, ^{90}Sr in shell, and ^{137}Cs in one meat sample. Failure to detect ^{137}Cs in meat samples results from the small amounts discharged, low sea water concentration, and the relatively low CF for ^{137}Cs in clam meat. Failure to detect ^{54}Mn when it was easily detectable in fish muscle, however, is surprising in view of the very large CF quoted for manganese in clam meat (10^4 to 5 x 10^4).*(11,15,20,34)*

Because ^{210}Po, an alpha-emitting naturally-occurring radionuclide, has been reported in shellfish muscle,*(48,49)* 5 shellfish samples were analyzed for ^{210}Pb and ^{210}Po, with the results given in Table 5.21. The ^{210}Po is in higher concentration in shellfish muscle than any radionuclide from plant effluents. The ^{210}Po in meat ranged from 230 to 500 pCi/kg fresh weight, and was concentrated in muscle relative to fluid by a factor of about 4. The concentration of ^{210}Pb in clam muscle varied from 20 to 70 pCi/kg fresh weight, and it was similarly concentrated in the muscle.

Average concentrations were 370 ± 90 pCi ^{210}Po/kg and 50 ± 20 pCi ^{210}Pb/kg in the muscle, and 100 ± 20 pCi ^{210}Po/kg and 13 ± 3 pCi ^{210}Pb/kg in fluid. Hence, the ^{210}Po is unsupported in shellfish muscle and fluid. The ^{210}Po/^{210}Pb activity ratios varied from 5 to 17, with an average ratio of 9. This indicates that the ^{210}Po is accumulated by shellfish from food rather than water, as concentrations of ^{210}Pb and ^{210}Po in coastal sea water indicate a ^{210}Po/^{210}Pb activity ratio below unity.*(49)* Phytoplankton and zooplankton, which are consumed by filter-feeding clams, contain relatively high levels of ^{210}Po and a ^{210}Po/^{210}Pb activity ratio ranging from 4 to 13, similar to that observed in clams.*(49,50)* High ^{210}Po levels may thus also be expected in finfish that consume mostly plankton.

The distribution of ^{210}Po in clam fluid was examined to determine if ^{210}Po was associated mainly with protein, as has been reported.*(51)* The ^{210}Po concentration of sample No. 18 was measured in fluid and in the liquid phase of the fluid after the protein had been removed by ultracentrifugation (see above). The ^{210}Po could not be measured directly in the protein fraction as it had previously been ashed at 450° C. The results of these analyses were:

	^{210}Po, pCi/kg	^{210}Pb, pCi/kg
Whole fluid	91 ± 3	14 ± 1
Supernatant liquid	17 ± 1	3 ± 1

The protein fraction, which consisted of only about 4 percent of the fluid mass (15 g protein/400 g fluid), is determined by difference to contain 80 percent of the ^{210}Po and ^{210}Pb, as was the case of ^{60}Co.

The concentration of radionuclides measured in whole barnacles (arthropoda) and annelid tubes from the coolant water and intake canals, and in the cluster of annelid tubes collected from Barnegat Bay near Watetown, are given in Table 5.22. These results indicate that these organisms concentrate ^{54}Mn, ^{58}Co, ^{60}Co and ^{90}Sr discharged from the station. The higher levels in the earlier samples reflect higher station discharges in the latter part of 1971.

Barnacles *(Pollicipes polymerus)* collected in the eastern Pacific Ocean have been reported to contain about 5 pCi/kg each of ^{54}Mn and ^{60}Co.*(52)* These levels reflect large concentration factors, 10^3-10^4, as the concentration of ^{54}Mn and ^{60}Co in sea water from fallout is very low. CF's based on concentrations measured in whole barnacles collected in January 1972 from the discharge canal and the average October-December 1971 hypothetical water concentrations in Oyster Creek* (see Appendix B.4), are:

A three-month discharge period was selected because mollusk excretion data indicate that the bulk of the radionuclides measured in these samples would be predominantly the result of station discharges during the previous 100 days.(45,53)*

Table 5.22 Radionuclide Concentration in Barnacles and Annelid Tubes, pCi/kg Fresh Weight

Date collected	Location	^{54}Mn	^{58}Co	^{60}Co	^{90}Sr	^{137}Cs
			Arthropoda			
1/18/72	discharge canal	1200 ± 50	600 ± 30	2700 ± 90	2100 ± 200	100 ± 20
1/18/72	intake canal	200 ± 20	< 50	300 ± 30	680 ± 200	< 50
4/11/72	discharge canal	300 ± 20	< 40	1000 ± 100	380 ± 40	< 100
			Annelid Tubes			
1/18/72	intake canal	300 ± 20	< 50	400 ± 30	800 ± 200	< 50
4/11/72	intake canal	300 ± 20	< 70	300 ± 25	300 ± 40	< 100
4/18/72	Site H	320 ± 20	< 40	200 ± 20	NA	130 ± 20

Notes

1. ^{89}Sr < 200 pCi/kg
2. < values are 3σ and ± values are 2σ of the count rate.
3. NA - Not Analyzed

^{54}Mn =	800	^{90}Sr =	1600
^{58}Co =	1600	^{137}Cs =	100
^{60}Co =	900		

Background concentrations of ^{90}Sr and ^{137}Cs (Section 5.2.3) were included in the average hypothetical canal water values for these calculations. All estimated CF's, except for ^{137}Cs, approach or exceed 10^3. Barnacles, because of these large CF's and their immobility, should be good indicators for radionuclides discharged by the station.

Radionuclides are in barnacles from both canals, reflecting recirculation of station effluents. The higher concentrations of ^{54}Mn and ^{60}Co in the barnacles collected from the discharge canal in January 1972, indicate that only 10 to 15 percent of the effluent was recirculating through the intake canal during this period.

5.5.4 *Hypothetical radionuclide concentration in shellfish.* Although shellfish do not grow in the discharge canal, the concentrations of radionuclides in shellfish that would be so exposed to radioactive effluent from the station were computed to indicate possible critical radionuclides. These calculated concentrations are given in Table 5.23.

Calculated hypothetical concentrations are based on concentration factors for marine mollusks,*(20,34)* the estimated annual average 1971–1973 concentrations of radionuclides in discharge canal water (Section 5.2.4), and the assumption that radionuclides in shellfish meat had reached equilibrium with radionuclide concentrations in the canal. These hypothetical concentrations will have the same associated uncertainties as those calculated for fish (Section 5.4.5).

A comparison of the concentrations measured in clam muscle with the hypothetical concentrations indicate the latter to be higher, particularly for ^{54}Mn, ^{55}Fe and ^{65}Zn. This is to be expected since it is unlikely that equilibrium has been attained and some dilution occurs as the water moves into the mouth of the creek to Site B, the location of the closest clam bed. The hypothetical ^{60}Co concentration is 2.5 times that measured in the samples, but the hypothetical concentration of ^{54}Mn is 210 times the minimum detectable level of 20 pCi/kg. Possibly the manganese is in a form that is not available for uptake by the clam, but the ^{54}Mn levels detected in fish suggest that the CF for shellfish muscle is excessive for Barnegat Bay. The turnover rate of manganese in clams is faster than that for cobalt,*(45)* but as McCurdy concluded, is not sufficiently rapid to explain the observed large ^{60}Co/^{54}Mn activity ratio.*(6)*

If one considers that:

1) twice as much ^{60}Co as ^{54}Mn is discharged and the percent of ^{60}Co existing in the discharge canal in a soluble form is 1 to 3 times the soluble percent of ^{54}Mn (Section 4.4.4), the amount of ^{60}Co available for uptake is 2 to 6 times that of ^{54}Mn, assuming only the soluble chemical species are available for uptake,
2) ^{54}Mn is eliminated from clam muscle at a rate roughly 2.5 times that of ^{60}Co,*(45,53)* and
3) the average concentrations of ^{60}Co and ^{54}Mn in clam muscle are 180 pCi/kg and < 20 pCi/kg, respectively,

Table 5.23 Hypothetical Radionuclide Concentrations in Shellfish Muscle

Radionuclide	Annual average concentration in water,* pCi/l	Concentration factor**	Hypothetical concentration in shellfish,† pCi/kg	Percent of limit††
^{3}H	34.6	1	35	<0.001 TB
^{14}C	0.0073	4,700	34	<0.001 TB
^{32}P	0.056	6,000	340	0.23 B
^{51}Cr	0.22	440	97	<0.001 GI
^{54}Mn	0.35	12,000	4,200	0.84 GI
^{55}Fe	0.49	9,600	4,700	0.12 S
^{59}Fe	0.026	9,600	250	0.08 GI
^{58}Co	0.085	600	51	0.01 GI
^{60}Co	0.76	600	460	0.18 GI
^{64}Cu	0.077	5,000	380	0.03 GI
^{65}Zn	0.015	11,000	160	0.01 TB
^{76}As	0.11	650	72	0.07 GI
^{89}Sr	0.22	1	0.22	<0.001 B
^{90}Sr	0.030	1	0.03	0.001 B
^{91}Sr	0.034	1	0.03	<0.001 GI
^{95}Zr	0.013	2	0.03	<0.001 GI
^{95}Nb	0.021	7	0.15	<0.001 GI
^{99}Mo	0.16	60	10	0.001 GI
^{99m}Tc	0.16	100	16	<0.001 GI
^{103}Ru	0.0078	3	0.023	<0.001 GI
^{105}Rh	0.11	100	11	0.002 GI
^{110m}Ag	0.0064	7,100	45	0.03 GI
^{124}Sb	0.002	1,000	2	0.002 GI
^{131}I	0.27	50	14	0.93 T
^{133}I	0.22	50	11	0.22 T
^{134}Cs	0.54	8	4.3	0.003 TB
^{137}Cs	0.82	8	6.6	0.002 TB
^{140}Ba	0.11	3	0.3	<0.001 GI
^{141}Ce	0.032	360	12	0.003 GI
^{144}Ce	0.020	360	7	0.01 GI
^{239}Np	0.44	10	4.4	0.001 GI

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* From Section 5.2.4; ^{89}Sr and ^{90}Sr assumed to be the same ratio in 1971 and 1972 as in 1973.

** CF based on reference 20, except ^{3}H, ^{99m}Tc, ^{105}Rh and ^{239}Np are based on reference 34.

† The product of the values in columns 2 and 3.

†† The limit is based on an intake of 50 g fish per day that will result in an exposure equal to the Radiation Protection Guides recommended by the FRC$^{(40)}$: the RPG are 500 mrem/yr for thyroid (T) and bone (B), and 170 mrem/yr for all other critical organs; total body (TB), gastrointestinal tract (GI), and spleen (S).

the CF of ^{54}Mn at best can be no greater than 1.7 times that of ^{60}Co, or about 1000, assuming a ^{60}Co CF of 600.

The average radionuclide concentrations measured in clam meat are listed in the second column of Table 5.24 relative to a 50 g sample, the assumed average daily intake by persons eating shellfish.*(54)* The average ^{90}Sr concentration listed for the meat is based on the average clam shell concentration of 190 pCi/kg and a shell/meat ratio of 16 (see Section 5.5.3). Subtracting the concentrations in the background clams from Great Bay, 105 pCi ^{90}Sr/kg shell ÷ 16, 270 pCi ^{14}C/kg and 21 pCi ^{210}Po/kg, gives the amount in meat of Barnegat Bay clams due to effluents from the station. These values are listed in the third column. The fourth column lists the hypothetical concentrations from Table 5.23. The next three columns list the estimated radiation dose rates: the total, that resulting from station effluents, and that based on the hypothetical concentrations. These dose rates were calculated using the daily intake-dose rate relationships given in Appendix F.2.

Except for ^{90}Sr, the hypothetical dose rates exceed those based on measured concentrations and would indicate that radioiodines, ^{32}P, ^{54}Mn and ^{90}Sr are the critical radionuclides. The dose rate from ^{54}Mn has been shown to be greatly overestimated; large minimum detectable levels prevent comparisons for the radioiodines and ^{32}P values. Also, it is not possible to confirm the ^{90}Sr dose to the bone as it could not be measured in the meat at the level inferred from the shell measurements. An effort should be made in future studies to measure these radionuclides. The largest dose rates are delivered by ^{210}Po, a naturally-occurring radionuclide. The dose rates from radionuclides in station discharges are relatively small compared to those resulting from ^{210}Po.

A summation of the annual doses from station discharges, given in Table 5.24 for each critical organ, compare with those calculated by the USAEC as follows:

Critical organ	Annual dose based on measured conc., mrem	Hypothetical annual dose, mrem	Annual dose calculated by USAEC,*(3)* mrem*
Total Body	<0.1	<0.1	0.03
Thyroid	<5	5.1	0.5
GI tract	0.1	1.8	0.3
Bone	1.0	1.1	0.03

*Based on a daily intake of 25 g of clam meat.

Table 5.24 Radiation Dose from Eating Clam Meat

Radio-nuclide	Average concentration, pCi/50 g			Radiation dose rate, mrem/yr			Critical organ
	total	from station	hypothetical*	total	from station	hypothetical*	
^{14}C	14	< 5	1.7	<0.1	<0.1	<0.1	Total Body
^{32}P	< 20	< 20	17	< 1.3	< 1.3	1.1	Bone
^{54}Mn	< 1	< 1	210	<0.1	<0.1	1.4	GI(LLI)
^{55}Fe	< 5	< 5	235	<0.1	<0.1	0.2	Spleen
^{59}Fe	< 2	< 2	13	<0.1	<0.1	0.1	GI(LLI)
^{60}Co	10	10	23	0.1	0.1	0.3	GI(LLI)
^{90}Sr	0.6**	0.3**	<0.1	2.0	1.0	<0.3	Bone
^{131}I	< 0.8	< 0.8	0.7	<5^{+}	<5^{+}	4^{+}	Thyroid
^{133}I	ND^{++}	ND^{++}	0.6	---	---	1.1^{+}	Thyroid
^{210}Po	21	0	0	21	0	0	Spleen
				18	0	0	Kidney
				5	0	0	Liver
				3	0	0	Bone
				0.7	0	0	Total Body
				0.5	0	0	GI(LLI)

* Based on the hypothetical concentrations given in Table 5.23; only those radionuclides that deliver 0.1 mrem/yr or more are included.

** Based on the average ^{90}Sr concentration in the shells and a shell/muscle ratio of 16.

[+] Dose is based on a child's thyroid (see Appendix F.2).

[++] ND - not detected.

The dose rates show reasonable agreement, considering that the AEC calculations were based on a daily intake of 25 g clam meat. Phosphorus-32, which the AEC did not consider, is responsible for the larger hypothetical bone dose, and failure to detect ^{54}Mn in any samples established the hypothetical GI dose to be overestimated. These dose rates are all less than 2 percent of the Radiation Protection Guides recommended by the FRC: 500 mrem/yr to the bone and thyroid and 170 mrem/yr to all of the other critical organs.*(40)* As discussed above, for all critical organs except the thyroid, these dose rates are small compared to that due to ^{210}Po. For this reason, it is recommended that, in addition to ^{32}P and ^{131}I, future surveillance studies include measurements of ^{210}Po in shellfish meat to determine the relative significance of the exposures resulting from radionuclides discharged by the station.

5.6 Radionuclides in Crustacea

5.6.1 *Introduction.* The blue crab, *Collinectes sapides*, is taken from Barnegat Bay and the intake and discharge canals by both commercial and sport fishermen. The total harvest of blue crabs from the area was estimated to be 29,600 kg in 1969 and 32,700 kg in 1970.*(3,5)* Crabs are taken in large numbers by individuals fishing from the Highway 9 bridge over the discharge canal and along its banks.

Crab samples are not included in the station's aquatic environmental monitoring program.*(3)* McCurdy analyzed a few crab samples and detected very little radioactivity in the edible portions.*(6,7)* Even though little evidence of radionuclide uptake exists,*(55)* blue crabs were studied because of their abundance in Barnegat Bay and the discharge canal and the significant amounts eaten by the local population.

5.6.2 *Collection and analysis.* Blue crabs were collected by trawl in the fall of 1971 and again in April and July of 1972. A total of 13 samples, consisting of 5 to 35 specimens each, were obtained from the discharge and intake canals, Barnegat Bay and Great Bay. Samples from the latter were considered controls. A description of the crab samples is given in Table 5.25. The crabs were frozen, returned to the laboratory, thawed and dissected into meat, gut and stomach, gills and skeleton. Radiochemical and stable chemical analyses were performed as described previously.

5.6.3 *Results and discussion.* No radionuclides attributable to the Oyster Creek station were detected in the muscle, gills, gut and stomach. Naturally-occurring ^{40}K and small concentrations of ^{137}Cs from fallout were observed in crab meat at an average concentration of 2.8 ± 0.4 g K*/kg and 30 ± 12 pCi ^{137}Cs/kg fresh weight. The average ^{14}C concentration was 17 ± 2 dpm/g C (470 ± 100 pCi/kg fresh weight), and is totally attributed to cosmic ray production and fallout.*(22)* The minimum detectable levels of radionuclides in crab meat at the 3-standard deviation confidence level were: ^{60}Co < 60 pCi/kg, ^{54}Mn < 50 pCi/kg, and ^{65}Zn < 80 pCi/kg. Because of the absence of measurable quantities and the difficulty in separating meat from exoskeleton, crabs were not collected after the July 1972 field trip.

Some exoskeletons contained measurable quantities of ^{54}Mn and ^{90}Sr exceeding those measured in control samples from Great Bay, as shown in Table 5.25. Manganese-54 was observed in the skeleton of crabs collected from the discharge canal, the south branch of Forked River (intake canal) and from Sites B, H and G in Barnegat Bay. Concentrations ranged from 80 pCi/kg to 440 pCi/kg fresh weight, and were somewhat higher in the fall of 1971 than in the summer of 1972. High ^{54}Mn levels in the crab exoskeleton relative to interior body parts have previously been observed and attributed to both surface adsorption of MnO_2 from surrounding water and the possible substitution of Mn for Ca in the lattice of the chitin skeleton.*(56)*

Crabs were very scarce during April 1972, having not recovered from hibernation. The only sample in Barnegat Bay collected during this period were 5 crabs from near Cedar Creek, Site G, which contained no measurable quantities of ^{54}Mn, as might be expected.

The average concentration of ^{90}Sr measured in the exoskeleton of control crabs from Great Bay was 110 ± 30 pCi/kg or 19 ± 5 pCi ^{90}Sr/mg Sr. The levels of ^{90}Sr in the samples obtained from Barnegat Bay in the vicinity of the mouth of Oyster Creek (Sites D, B, E, F, G, H) range from 35–95 pCi ^{90}Sr/mg Sr, and exceeds the background concentration in some cases by more than 5 times.

The average stable strontium and calcium skeletal concentrations were 5.4 ± 0.4 mg/kg and 0.42 ± 0.03 g/kg, respectively, with an average Sr/Ca ratio of 12.8 ± 0.7 mg Sr/g Ca. Assuming an average Sr/Ca ratio in the bay water of 20 ± 1 mg Sr/g Ca (see Section 5.2.2), results in an observed ratio for the exoskeleton of 0.64 ± 0.05. Concentration factors for strontium and calcium were calculated to be 1.0 and 1.6, respectively, using the average concentrations of strontium and

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*Calculated by measuring the ^{40}K concentration and assuming 848 pCi ^{40}K/g K

Table 5.25 Radionuclide and Stable Element Concentrations in Crab Exoskeletons

Sample No.	Collection date	Location*	No. of specimens	Sr, g/kg	Ca, g/kg	^{54}Mn, pCi/kg	^{90}Sr, pCi/kg
1	9/23/71	B	13	0.0050	0.45	290 ± 30	170 ± 20
2	9/23/71	C	5	0.0049	0.40	< 60	240 ± 50
3	10/18/71	D	16	0.0060	0.48	440 ± 50	570 ± 60
4	10/21/71	E	22	0.0054	0.42	320 ± 30	320 ± 30
5	10/19/71	F	6	0.0045	0.34	< 60	180 ± 50
6	10/20/71	I	35	NA	NA	< 40	NA
7	10/21/71	G	13	0.0058	0.43	240 ± 40	470 ± 50
8	4/17/72	GB-X	10	0.0059	0.44	< 20	90 ± 10
9	4/19/72	G	5	0.0058	0.45	< 60	240 ± 30
10	7/11/72	GB-X	12	0.0058	0.46	< 30	130 ± 20
11	7/11/72	H	6	0.0056	0.42	110 ± 20	200 ± 20
12	7/12/72	B	8	0.0052	0.40	150 ± 50	250 ± 30
13	7/12/72	G	16	0.0052	0.42	80 ± 30	200 ± 20

*Locations are shown on map in Figures 5.1 and 5.2.

Notes:

1. Concentrations based on fresh weight.
2. ± values are 2σ of count rate; < values are 3σ of count rate.
3. Error of Ca and Sr values are 2% and 3%, respectively.

calcium in bay water given in Section 5.2.2 with those above for the exoskeleton. Crab skeletons would thus not be useful indicators of strontium or calcium in the environment. Relating the concentration of nuclides in crab exoskeleton to station discharges over any period of time may be difficult because, in addition to the normal turnover of radionuclides in the calcareous material of the crab, periodic molting will result in a sudden loss of all accumulated nuclides.

At the present operating level and conditions at Oyster Creek, the consumption of crab meat by man does not constitute a measurable pathway.

5.7 Radionuclides in Sediment

5.7.1 *Sample collection and preparation.* On five field trips from October 1971 to October 1973, a total of 59 sediment samples were collected from the discharge canal, intake canal, throughout Barnegat Bay and in Great Bay at locations shown in Figures 5.3 and 5.4. They were obtained with Petersen or Eckman dredges at depths of 2–10 cm. During the first trip (October 1971) the largest number of samples (31) was obtained throughout Barnegat Bay to survey the range of accumulated reactor-produced radionuclides in sediment. A submersible 10- x 10-cm NaI(Tl) probe and associated portable multichannel pulse-height analyzer were used to locate areas where build-up of ^{60}Co was detectable.* *(26)*

On April 18, 1972, several 2.5-cm-diameter core samples were taken at Site 4 in the discharge canal (see Figure 5.3). In the laboratory, they were separated into 3 clearly visible zones (0–6 cm, 6–12 cm, and 12–30 cm) and each zone was combined to yield samples sufficiently large for gamma-ray analysis.

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*We thank Mr. Sam Windham, Eastern Environmental Radiation Facility, USEPA, for providing the instrument and participating in the measurements.

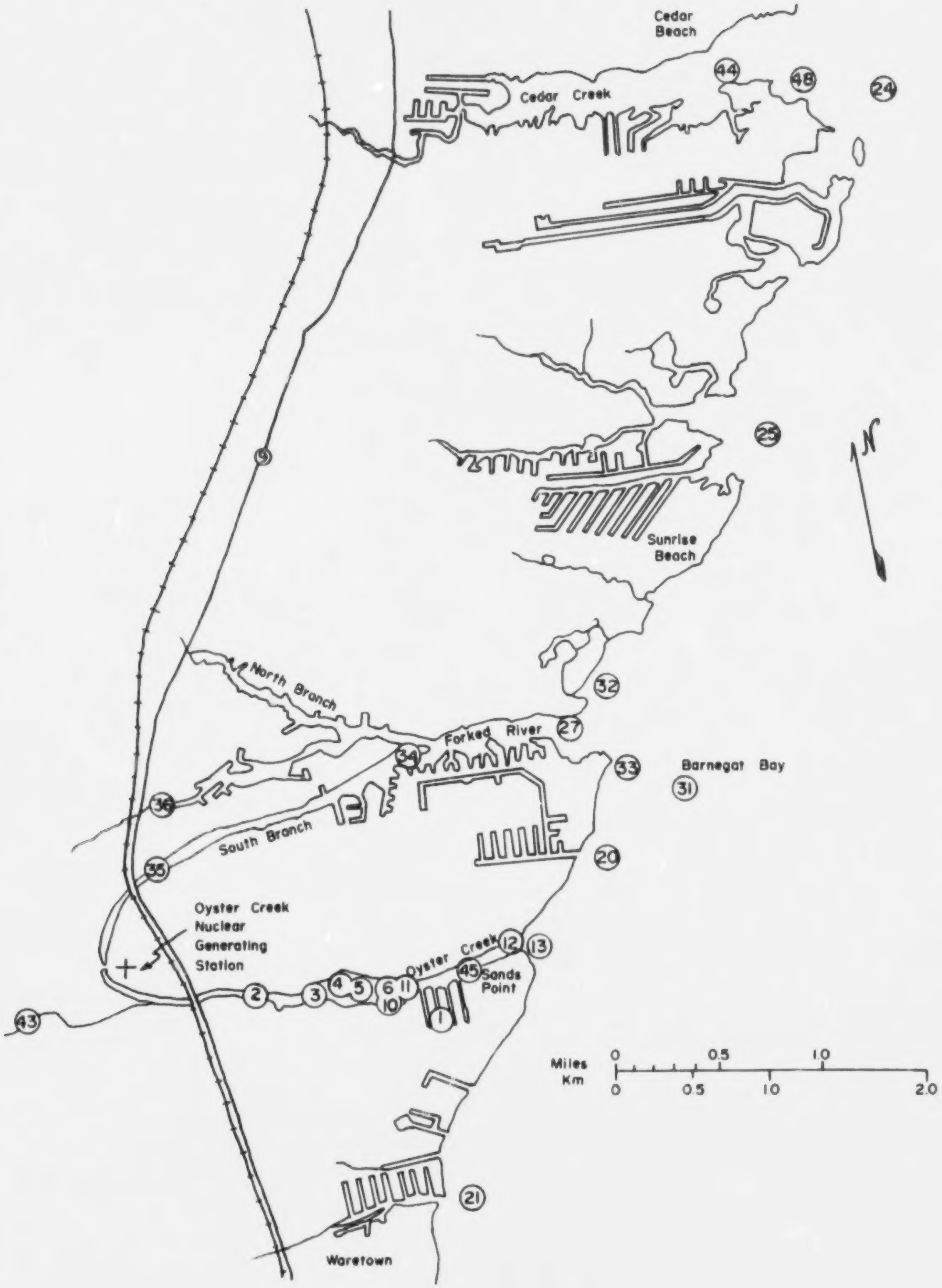
Cedar Beach
44
48
24
Cedar Creek
25
N
9
Sunrise Beach
North Branch
32
Forked River
27
34
33
Barnegat Bay
31
36
South Branch
20
35
Oyster Creek Nuclear Generating Station
Oyster Creek
12
13
45
Sands Point
2
3
4
5
6
11
10
1
43
Miles
Km
0
0.5
1.0
0
0.5
1.0
2.0
21
Waretown

Figure 5.3 Sediment sampling sites near the Oyster Creek Nuclear Generating Station.

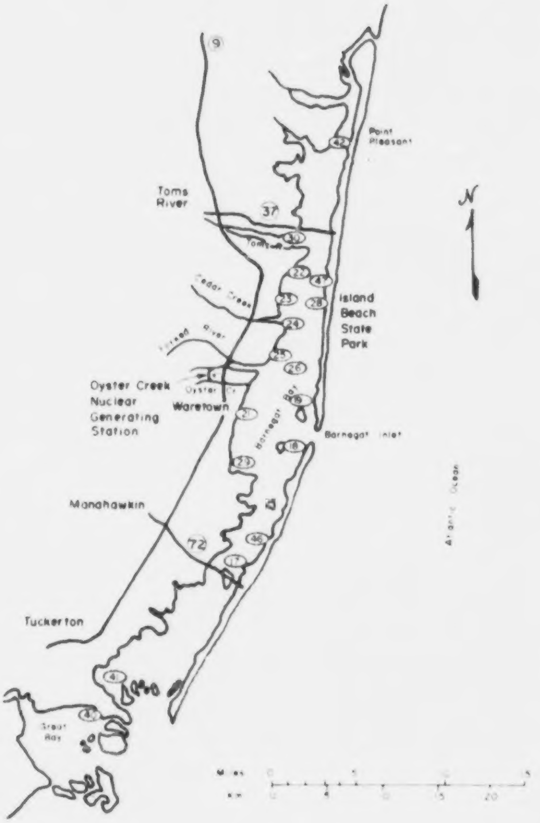

Figure 5.4 Distant sediment sampling sites at the Oyster Creek Nuclear Generating Station.

Sediment samples were air-dried in the laboratory at room temperature (20° C) by spreading thinly on plastic sheets for 5–10 days. Air drying was preferred to oven drying to minimize cementation (aggregation) effects on subsequent determination of particle size distribution. The dried samples were screened through a number 10 mesh sieve (2.0 mm) and further homogenized by shaking.

5.7.2 *Description of sediment samples.* To define the sediment samples geochemically, aliquots collected in the discharge canal, intake canal, Barnegat Bay and Great Bay during the October-November 1972 field trip (OC B-300 series) were analyzed for pH, cation exchange capacity, particle size distribution and organic content.* In addition, samples 305 and 310 were analyzed in both the original wet and laboratory dried states. Analytical methods used for these analyses were standard techniques recommended jointly by the American Society of Agronomy and the American Society for Testing and Materials*(57)* and have been described in a previous report.*(26)*

The results of the mineralogical analyses of these 11 samples are given in Table 5.26. Sediments collected from the wide area of the discharge canal (locations 4, 5, 6), intake canal (location 39), Cedar Creek (location 44), Little Egg Harbor (location 41) and Great Bay (location 40) were relatively rich in organic matter and had a high cation-exchange capacity (CEC). Sandy material was also present in some of these areas as shown by a comparison of samples 300 and 301 collected from one location in Great Bay (location 40). It was not possible to separate physically the fine organic and mineral components of these samples. Multiple regression analysis of the CEC as functions of organic carbon and total clay content indicated that the organic carbon and clay fractions contributed nearly equally to the total CEC, about 54 and 46 percent, respectively.

Sample 310 was collected at Site 43 in the fresh water area of Oyster Creek above its confluence with the discharge canal (see Figure 5.3). The creek passes through a cedar swamp in this area, and the water was brown in color and acidic (pH = 4.1), presumably due to tannic acid leached from decaying cedar logs in the stream. This is reflected in the pH 4.2 of the sediment. The effects of this acidic water of the sorption of radionuclides on sediment downstream in the discharge canal portion of Oyster Creek are probably minimal, as the contribution of fresh water from Oyster Creek to that in the discharge canal is small (see Section 5.1.1).

The clay mineral composition of sample 305 was determined by x-ray crystallography of preferred-oriented aggregate clay fractions on ceramic plants. This sample was from the wide segment of Oyster Creek, location 6, and considered typical of sediments from this area of the creek. The results are given in Table 5.27. The failure to detect any chlorite mineral in this sediment sample suggests that these sediments were of terrestrial rather than marine origin. This is expected in an estuarine environment where much of the material in the sediments has originated from runoff through adjacent fresh water tributaries, and in this case from circulating bay water containing suspended terrestrial material that had deposited in the bay at some earlier time.

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*We thank Professor L. Wilding, Department of Agronomy, Ohio State University, for performing these analyses.

Table 5.26 Mineralogical Analysis of Sediment Samples

Sample No.	Location	pH	Textural class	Cation exchange capacity meq/100 g	% Carbonates (as $CaCO_3$)	% Organic carbon	% Organic matter	Particle size distribution Clay < 2 μ	Silt 2-50 μ	Sand 50-2000 μ
300	40	7.0	loam	18.6	0.6	1.15	1.98	21.6	47.5	30.9
301	40	7.9	coarse sand	0.4	0.4	0.10	0.17	0.7	0.6	98.7
302	41	7.2	v. fine silt	10.2	1.1	2.24	3.85	9.3	17.4	73.3
303	4	6.6	fine silt	16.9	1.1	3.04	5.23	11.6	21.0	67.4
304	5	6.5	loam	21.6	1.0	3.52	6.05	17.1	33.3	49.6
305	6	6.8	loam	29.1	1.4	4.71	8.10	24.3	48.8	26.9
306	39	6.4	silt	34.0	1.6	4.69	8.07	25.6	69.8	4.6
307	44	6.0	silt	43.2	0.9	6.84	11.76	27.1	68.4	4.5
308	22	7.0	loam	15.1	3.1	2.63	4.52	14.4	42.9	42.7
309	42	6.1	silt	14.6	1.1	2.41	4.14	10.6	54.3	35.1
310	43	4.2	fine sand	23.2	< 0.1	6.88	11.83	1.7	8.7	89.6

Notes:

1. Textural classification is empirical, based on observation by qualified soil scientist.
2. % organic carbon is corrected for inorganic carbonates (calcite and dolomite).
3. % organic matter is % organic carbon times 1.72.
4. For particle size distribution, air dried portions of sample were electrolyte-dispersed in water by sodium hexametaphosphate (calgon).

Table 5.27 Clay Mineralogy of Sample 305 from Oyster Creek

Basis of calculation	Clay Percentages				
	Expandables (montmorillonite) + other species	Mica (Illite)	Kaolinite	Quartz	Amorphous**
X-ray crystalline clay fraction	31	45	16	8	---
Total clay fraction	24	36	13	6	21

* Sample from Location 6.

** Weight loss on treatment with boiling 0.5 N NaOH. Clay percentages are estimated to be within ± 5%.

To determine the effects of sample preparation on particle size distribution, aliquots of samples 305 and 310 were analyzed in the original wet state and in the laboratory dried form. The wet and dried samples were dispersed with both water and sodium hexametaphosphate (calgon), an electrolyte, prior to the particle size determination. The results, listed in Table 5.28, do reflect some differences due to sample preparation, but the differences are not large. The wet form water-dispersed samples probably better represent natural conditions than dry or electrolyte-dispersed forms.

5.7.3 *Radioactivity measurements.* Radionuclides that emit gamma-rays were analyzed with 54-cc or 85-cc Ge(Li) detectors and a 4096-channel spectrometer. Generally, 400 ml aliquots of dried sediment were analyzed 1000 min. The Ge(Li) detectors were calibrated with aqueous solutions, as previous evaluation had indicated that self-absorption (density) errors were 10 percent or less for these types of

Table 5.28 Effects of Sample Preparation and Dispersion Technique on Particle Size Analysis

Sample No.	Preparation form	Dispersant	% Particle size distribution		
			Clay (< 2 μ)	Silt (2-50 μ)	Sand (50-2000 μ)
305	Dry	Electrolyte	24.3	48.8	26.9
	Dry	Water	21.0	49.9	29.1
	Wet	Electrolyte	24.9	43.4	31.7
	Wet	Water	16.2	50.7	33.1
310	Dry	Electrolyte	1.7	8.7	89.6
	Dry	Water	0.6	16.0	83.4
	Wet	Electrolyte	1.9	13.2	84.9
	Wet	Water	2.6	12.6	84.8

Notes:

1. Electrolyte dispersant is sodium hexametaphosphate (calgon).
2. Dry-electrolyte combination is the standard ASTM procedure.
3. Sample no. 305 is from brackish water; 310 was collected upstream on Oyster Creek in a fresh water area.

samples.*(26)* Since denser, sandier samples (density $> \sim 1.5$ g/cc) invariably contained little radioactivity, statistical counting errors tend to obscure any self-absorption error. Therefore, corrections for self-absorption were not included in the calculations.

Naturally-occurring ^{40}K, ^{226}Ra, and ^{232}Th are reported for all sediment samples. Potassium-40 and ^{226}Ra were measured directly by their 1462 keV and 186 keV gamma-ray peaks, respectively. However, ^{232}Th was measured indirectly using the 909 keV gamma-ray peak of its ^{228}Ac daughter and assuming that secular equilibrium existed. Because thorium isotopes are insoluble in a sea water environment, which is not the case for radium isotopes, this assumption is probably not valid and more ^{232}Th was present in the sediment samples than indicated by the results.*(58)*

Strontium-90, measured only in 5 samples from the first field trip because concentrations were so low, was determined by acid leaching 5-g aliquots, precipitating $SrCO_3$, and beta counting the measured ^{90}Sr plus ^{90}Y daughter activities.*(27)* Fine, calcareous shell fragments in all sediment samples were too small and numerous to remove.

5.7.4 ***Results and discussion of analyses.*** Radionuclide concentrations measured in the 59 sediment samples collected during the two-year study from the discharge canal, intake canal, Barnegat Bay and Great Bay are given in Table 5.29. Cobalt-60 was the most widely distributed radionuclide attributable to the station. Concentrations ranged from 0.26 to 18.6 pCi/g in the discharge canal and decreased in the bay with distance to a concentration less than detectable at the southern (Little Egg Harbor) and northern (Sloop Point) extremities. In addition, ^{54}Mn, ^{134}Cs and ^{137}Cs in excess of background were observed in many of the samples from the discharge canal, intake canal, and near the west shore of Barnegat Bay between Waretown and Cedar Creek (see Figure 5.3). No ^{58}Co was observed in any samples (<0.1 pCi/g), and the ^{125}Sb observed in a few samples is attributable to fallout. The presence of ^{60}Co and ^{54}Mn in the intake canal sediments is evidence of recirculation of effluent discharged by the station, as observed in algae and fish samples (see Sections 5.3.3 and 5.4.4). In general, the concentrations of ^{54}Mn, ^{60}Co and ^{137}Cs agree with those reported by McCurdy (see Section 5.1.4), and confirm his observation of station effluent recirculation.*(7)*

Concentrations of ^{90}Sr in five sediment samples obtained during the October 1971 field trip were only 0.1 to 0.2 pCi/g. Since levels did not appear elevated in the discharge canal sediment and because samples contained calcareous shell fragments which tend to elevate the strontium levels, ^{90}Sr measurements were discontinued.

The average concentration of radionuclides measured in 4 background samples from Great Bay (location 40) are given in Table 5.30. Sample no. 301 was not included in the background averages because it consisted entirely of coarse sand, atypical of sediments collected from the Oyster Creek sites (see Table 5.26). A very small quantity of ^{60}Co, 0.02 ± 0.01 pCi/g, was observed in one background sample (No. 300), which is also attributed to atmospheric fallout from nuclear weapons tests. The relatively large standard deviations reflect considerable variability of concentrations between samples. This is not unexpected and has been discussed in an earlier report.*(26)*

The highest concentrations of radionuclides attributable to station operation were found at locations 4 to 10 in the wide area of the discharge canal and at locations 11 to 13 progressing downstream from the wide area to the mouth of the canal (see Figure 5.3). Little radioactivity was detected in the discharge canal above the wide area in the narrow channel where high stream velocity had washed out the finer particles, leaving only coarse sand. Sands are characterized by high density (> 1.5 g/cc) and the absence of fine particles, consisting of clay minerals and organic matter which account for most of the ion-exchange properties of soils (see Section 5.7.2). For example, the sediment was sandy (density 1.7 g/cc) 100 m above the wide area in the discharge canal and contained only 0.26 pCi ^{60}Co/g. Samples 3 and 4, however, collected a short distance downstream in the wide area, were less sandy (densities 1.4 and 1.2 g/cc, respectively) and contained 0.8 and 4.2 pCi ^{60}Co/g, respectively. Whether sorption occurred on suspended fine particles during transport down the canal to the wider area where they settle due to slower stream velocity or adsorption occured from the slower moving water along the silty bottom of the wide area cannot be ascertained from these data. Results reported in Section 4.4.4 would indicate the former most likely, as radionuclides discharged by the station were observed either to be highly associated with particulate matter at discharge or to become so soon after discharge.

Concentrations of ^{134}Cs and ^{137}Cs were significantly higher in the sediment collected in the vicinity of the station during October-November 1972. Based on the October 1973 samples, these concentrations remained relatively high throughout the following year. This was a consequence of the relatively large quantities discharged by the station between July and September 1972 when the liquid radwaste system was not operating properly (see Section 4.3.1 and Appendix

Table 5.29 Radionuclide Analyses of Oyster Creek Sediment Samples, pCi/g Dry Weight

Sample No.	Site	Dry Density	^{40}K	^{54}Mn	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{226}Ra	^{232}Th
					October 18-21, 1971					
1	1	0.91	7.1 ± 0.3	0.75 ± 0.14	4.9 ± 0.1	0.24 ± 0.07	<0.05	0.87 ± 0.03	2.4 ± 0.3	0.42 ± 0.08
2	2	1.71	0.8 ± 0.1	<0.09	0.26 ± 0.02	<0.05	<0.02	0.02 ± 0.01	0.8 ± 0.2	0.21 ± 0.04
3	3	1.35	1.9 ± 0.2	<0.17	0.82 ± 0.04	<0.07	<0.03	0.05 ± 0.01	1.2 ± 0.2	0.34 ± 0.04
4	4	1.15	8.4 ± 0.4	0.38 ± 0.15	4.2 ± 0.1	<0.12	<0.05	0.28 ± 0.02	1.6 ± 0.3	0.55 ± 0.10
5	5	1.20	9.7 ± 0.4	1.7 ± 0.2	9.0 ± 0.1	0.22 ± 0.08	<0.06	0.53 ± 0.03	1.6 ± 0.3	0.60 ± 0.10
6	6	0.97	13.7 ± 0.5	0.68 ± 0.19	5.0 ± 0.1	<0.14	<0.06	0.61 ± 0.03	2.1 ± 0.3	0.70 ± 0.10
10	10	0.88	16.0 ± 1.1	3.6 ± 0.3	18.6 ± 0.4	<0.26	<0.14	1.3 ± 0.1	1.9 ± 0.6	0.90 ± 0.40
11	11	1.01	16.1 ± 0.5	<0.26	1.2 ± 0.1	<0.12	<0.05	0.15 ± 0.02	2.3 ± 0.3	0.70 ± 0.10
12	12	1.00	14.6 ± 0.5	0.95 ± 0.19	5.0 ± 0.1	<0.18	<0.06	0.36 ± 0.03	1.8 ± 0.3	0.70 ± 0.10
13	13	1.39	5.0 ± 0.3	<0.18	5.3 ± 0.1	<0.08	<0.05	0.10 ± 0.01	1.4 ± 0.2	0.43 ± 0.06
17	17	1.24	12.6 ± 0.4	<0.11	0.10 ± 0.03	<0.06	<0.03	0.14 ± 0.02	1.0 ± 0.3	0.46 ± 0.05
18	18	1.16	13.1 ± 0.4	<0.21	0.19 ± 0.03	0.13 ± 0.04	<0.03	0.46 ± 0.02	1.7 ± 0.3	0.53 ± 0.06
19	19	1.71	2.1 ± 0.2	<0.12	<0.04	<0.04	<0.03	<0.01	0.6 ± 0.2	0.09 ± 0.01
20	20	1.54	1.0 ± 0.3	0.05 ± 0.02	0.23 ± 0.03	<0.06	<0.02	0.05 ± 0.01	0.5 ± 0.1	0.22 ± 0.05
21	21	1.36	5.7 ± 0.3	<0.11	0.61 ± 0.03	<0.04	<0.04	0.11 ± 0.02	1.4 ± 0.3	0.46 ± 0.06
22	22	1.24	5.9 ± 0.3	<0.09	0.10 ± 0.02	<0.07	<0.03	0.16 ± 0.02	1.3 ± 0.3	0.37 ± 0.05
23	23	1.39	5.2 ± 0.3	<0.03	0.13 ± 0.02	<0.05	<0.02	0.13 ± 0.02	0.3 ± 0.1	0.41 ± 0.05
24	24	1.59	0.6 ± 0.1	<0.04	0.04 ± 0.01	<0.03	<0.01	<0.01	0.3 ± 0.2	0.10 ± 0.03
25	25	1.12	14.5 ± 0.5	<0.12	0.37 ± 0.04	<0.09	<0.12	0.33 ± 0.02	1.7 ± 0.3	0.62 ± 0.07
26	26	1.49	7.3 ± 0.3	<0.09	0.09 ± 0.02	<0.07	<0.04	0.03 ± 0.01	1.4 ± 0.3	0.62 ± 0.06
27	27	0.99	14.8 ± 0.5	0.34 ± 0.13	1.6 ± 0.1	<0.11	<0.04	0.34 ± 0.03	1.9 ± 0.4	0.68 ± 0.09
28	28	1.30	4.1 ± 0.2	<0.08	0.09 ± 0.02	<0.06	<0.04	0.10 ± 0.01	1.3 ± 0.3	0.28 ± 0.05
29	29	1.22	14.0 ± 0.4	<0.12	0.54 ± 0.04	<0.09	<0.03	0.21 ± 0.02	1.6 ± 0.3	0.63 ± 0.07
30	30	1.17	13.7 ± 0.4	<0.16	0.04 ± 0.02	0.12 ± 0.05	<0.03	0.33 ± 0.02	1.8 ± 0.2	0.61 ± 0.07
31	31	1.38	12.0 ± 0.4	<0.10	0.23 ± 0.3	<0.07	<0.03	0.07 ± 0.02	1.7 ± 0.3	0.76 ± 0.07
32	32	1.19	14.0 ± 0.4	<0.10	0.14 ± 0.03	<0.09	<0.03	0.22 ± 0.02	2.1 ± 0.4	0.77 ± 0.07
33	33	1.58	3.2 ± 0.2	<0.08	0.23 ± 0.02	<0.05	<0.02	0.05 ± 0.01	0.9 ± 0.2	0.24 ± 0.03
34	34	1.01	14.4 ± 0.4	<0.18	1.00 ± 0.05	0.14 ± 0.04	<0.04	0.31 ± 0.03	2.0 ± 0.4	0.62 ± 0.07
35	35	0.97	8.5 ± 0.4	<0.18	1.7 ± 0.1	<0.10	<0.04	0.30 ± 0.03	2.4 ± 0.4	0.68 ± 0.06
36	36	1.22	1.9 ± 0.1	<0.06	0.03 ± 0.01	<0.06	<0.02	0.13 ± 0.02	1.2 ± 0.3	0.24 ± 0.03
					April 17-18, 1972					
100	40	1.15	17.2 ± 0.6	<0.04	<0.04	0.14 ± 0.04	<0.02	0.45 ± 0.03	1.2 ± 0.1	0.72 ± 0.08
101	4	1.04	13.6 ± 0.6	0.15 ± 0.03	0.85 ± 0.06	0.09 ± 0.05	<0.03	0.32 ± 0.03	0.8 ± 0.1	0.70 ± 0.10
104	5	0.88	9.5 ± 0.5	0.91 ± 0.06	7.6 ± 0.1	0.17 ± 0.07	<0.04	0.53 ± 0.04	1.0 ± 0.2	0.50 ± 0.10

Table 5.29 Radionuclide Analyses of Oyster Creek Sediment Samples, pCi/g Dry Weight (Cont'd)

Sample No.	Site	Dry Density	^{40}K	^{54}Mn	^{60}Co	^{125}Sb	^{134}Cs	^{137}Cs	^{226}Ra	^{232}Th
105	27	1.00	15.9 ± 0.8	0.51 ± 0.06	2.1 ± 0.1	0.17 ± 0.07	<0.05	0.47 ± 0.05	0.6 ± 0.2	0.60 ± 0.10
106	24	1.09	15.9 ± 0.5	<0.13	0.54 ± 0.04	0.16 ± 0.04	<0.04	0.32 ± 0.03	1.8 ± 0.3	0.67 ± 0.06
						July 10-11, 1972				
200	40	1.15	13.6 ± 0.5	<0.03	<0.02	<0.07	<0.04	0.34 ± 0.02	1.2 ± 0.2	0.60 ± 0.05
201*	5	0.83	9.1 ± 1.7	1.8 ± 0.3	13.8 ± 0.5	<0.4	<0.18	0.50 ± 0.10	2.2 ± 1.1	0.90 ± 0.50
202	12	1.29	3.7 ± 0.3	0.21 ± 0.03	0.88 ± 0.04	<0.05	<0.02	0.15 ± 0.02	0.7 ± 0.2	0.26 ± 0.05
203	21	1.50	1.0 ± 0.1	<0.05	1.3 ± 0.1	<0.05	<0.02	<0.02	1.0 ± 0.2	0.31 ± 0.04
204	24	1.23	1.6 ± 0.1	0.02 ± 0.01	0.05 ± 0.01	<0.02	<0.01	<0.01	0.3 ± 0.1	0.13 ± 0.02
205	27	0.87	13.2 ± 0.5	0.24 ± 0.06	1.7 ± 0.2	0.15 ± 0.05	<0.05	0.33 ± 0.03	1.9 ± 0.3	0.60 ± 0.10
206	45	1.69	0.6 ± 0.1	<0.04	0.04 ± 0.01	<0.03	<0.01	0.02 ± 0.01	0.5 ± 0.2	0.08 ± 0.02
207	46	1.54	1.4 ± 0.2	<0.03	<0.03	<0.03	<0.01	<0.01	0.6 ± 0.1	0.10 ± 0.03
208	47	1.68	1.2 ± 0.1	<0.04	<0.01	<0.03	<0.02	<0.01	0.4 ± 0.1	0.06 ± 0.02
209	48	1.74	0.3 + 0.1	<0.08	<0.04	<0.02	<0.02	<0.02	2.9 + 0.2	1.1 + 0.1
						October 31-November 2, 1972				
300	40	1.27	16.8 ± 0.3	<0.01	0.02 ± 0.01	0.14 ± 0.02	<0.01	0.34 ± 0.01	0.5 ± 0.1	0.70 ± 0.04
301	40	1.79	0.9 ± 0.1	<0.01	<0.01	<0.02	<0.01	<0.01	0.2 ± 0.1	0.04 ± 0.02
302	41	1.25	13.9 ± 0.5	<0.02	<0.03	0.09 ± 0.04	<0.02	0.08 ± 0.01	1.6 ± 0.2	0.68 ± 0.07
303	4	1.13	5.4 ± 0.3	1.8 ± 0.1	7.8 ± 0.1	<0.10	0.62 ± 0.04	1.3 ± 0.1	1.5 ± 0.4	0.50 ± 0.10
304	5	1.00	9.8 ± 0.4	1.7 ± 0.1	9.8 ± 0.1	<0.13	0.62 ± 0.04	1.6 ± 0.1	2.4 ± 0.4	0.60 ± 0.20
305	6	0.82	11.5 ± 0.6	2.0 ± 0.1	10.9 ± 0.2	<0.21	0.89 ± 0.07	2.0 ± 0.1	2.8 ± 0.5	0.50 ± 0.20
306	34	1.01	15.9 ± 0.5	<0.09	0.17 ± 0.03	<0.06	0.04 ± 0.02	0.41 ± 0.02	2.1 ± 0.3	0.80 ± 0.10
307	44	0.90	15.2 ± 0.6	0.19 ± 0.02	0.81 ± 0.05	<0.09	0.15 ± 0.03	0.51 ± 0.03	2.3 ± 0.4	0.60 ± 0.10
308	22	1.15	10.5 ± 0.4	<0.06	0.16 ± 0.02	0.14 ± 0.04	<0.03	0.44 ± 0.02	1.7 ± 0.3	0.60 ± 0.06
309	42	1.13	13.4 ± 0.5	<0.02	<0.03	<0.05	<0.02	0.22 ± 0.02	2.0 ± 0.3	0.55 ± 0.07
310	43	1.18	1.6 ± 0.1	<0.01	<0.01	<0.02	<0.01	0.04 ± 0.01	1.3 ± 0.1	0.34 ± 0.02
						October 30-31, 1973				
400	40	1.11	14.0 ± 0.05	<0.02	<0.02	0.04 ± 0.02	<0.03	0.26 ± 0.02	1.4 ± 0.3	0.51 ± 0.05
404	5	1.11	9.9 ± 0.4	1.4 ± 0.1	7.4 ± 0.1	0.13 ± 0.05	0.34 ± 0.03	1.1 ± 0.1	1.7 ± 0.3	0.60 ± 0.10
405	6	1.15	10.5 ± 0.4	1.5 ± 0.1	6.8 ± 0.1	0.09 ± 0.05	0.23 ± 0.02	0.93 ± 0.04	1.4 ± 0.3	0.60 ± 0.10

Notes:

1. ± values indicate analytical error expressed at 2σ and < values are minimum detectable concentrations at 3σ counting error.
2. ^{90}Sr was determined in samples 1, 2, 3, 19 and 30 to be 0.16 ± 0.08, 0.12 ± 0.09, 0.16 ± 0.06, 0.11 ± 0.06, and < 0.12 pCi/g, respectively.
3. Site 40 is in Great Bay (Background).

Table 5.30 Average Background Concentrations of Radionuclides in Great Bay Sediment Samples

Radionuclide	Concentration, pCi/g	Radionuclide	Concentration, pCi/g
^{40}K	15 ± 2	^{134}Cs	< 0.02
^{54}Mn	< 0.02	^{137}Cs	0.35 ± 0.08
^{60}Co	< 0.02	^{226}Ra	1.1 ± 0.4
^{125}Sb	0.09 ± 0.06	^{232}Th	0.6 ± 0.1

Note: ± values are the standard deviation of individual observations; < values are three times the square root of twice background.

B.4). The results of these sediment samples, collected at a one-year interval, reflect a one-year decay of ^{134}Cs and a loss of both radionuclides due to transport down the discharge canal to Barnegat Bay. This is an example of the integrating nature of sediment and its value as an indicator of atypical plant discharges.

If the samples from the discharge canal are mineralogically comparable to those collected from Great Bay, the average concentration of ^{137}Cs measured in background samples subtracted from the concentrations measured in the discharge canal gives the quantity due to plant discharges. The average ^{134}Cs/^{137}Cs activity ratio for those samples collected during October-November 1972, subtracting ^{137}Cs background, is 0.66 ± 0.08 (± 1σ). This activity ratio is similar to that in station effluents for the four-month period preceeding collection during high radiocesium discharges of 0.70 ± 0.05 (see Appendix B.4). The smaller ^{134}Cs/^{137}Cs ratio observed in the two samples collected during October 1973, 0.42 ± 0.02, may be the result of radioactive decay by ^{134}Cs, as the station discharged very little radiocesium (< 0.1 Ci) during the 12-month sampling interval.

Considering all sediment samples in which both ^{54}Mn and ^{60}Co were measured, the ^{60}Co/^{54}Mn activity ratio was calculated to be 5.8 ± 1.7. There appeared to be no significant difference in the ratio relative to sampling location or time. The ^{60}Co/^{54}Mn activity ratio in station effluent during the study was also relatively constant, but the average activity ratio discharged, 1.8 ± 0.2, was significantly lower than that measured in sediment. This difference can be attributed to: (1) greater adsorption of ^{60}Co relative to ^{54}Mn on sediment; (2) greater desorption of ^{54}Mn from the sediment relative to ^{60}Co; or (3) the more rapid radioactive decay of ^{54}Mn. Because all measurements made in Oyster Creek indicated nearly equal and total association of ^{54}Mn and ^{60}Co with particles (see Sections 4.4.4 and 4.4.5), the difference is attributed to the latter.

The measurements of the composite core sample are listed in Table 5.31 relative to three increments of depth. Radionuclides present in station liquid effluents, ^{54}Mn and ^{60}Co, are in the sediments to a depth no greater than 12 cm. These radionuclides are primarily concentrated in the top 6 cm layer, which suggests either recent deposition or a slow turnover rate of bottom materials. The core sections chosen for analysis are quite large, and future studies should consider increasing the sensitivity of measurement to enable analyzing thinner sections for more definitive information on the radionuclide profile in the sediments. Periodic core sampling over a larger area in the wide portion of the discharge canal would provide additional useful information.

Previous studies have proven the underwater probe to be a convenient device for surveying sediments *in situ* because the location and distribution of radioactivity can be determined immediately.*(26,29)* Analysis of sediment collected at the locations examined by the probe then provide information concerning radionuclide identity and quantity. The counting efficiency of the probe for ^{60}Co has been found to vary from 290 to 800 cpm per pCi/g with location, which would be expected from the nonuniform vertical and horizontal distribution of radionuclides in sediments.*(26,29)*

Table 5.31 Radionuclide Concentrations in Composite Core Samples, pCi/g Air-Dried

Depth	Composition	^{60}Co	^{54}Mn	^{137}Cs
0-6 cm	silt	3.8	0.3	0.3
6-12 cm	silt	1.4	0.1	< 0.1
12-30 cm	sand	< 0.03	< 0.03	< 0.03

Note: Composite of 9 core samples collected in the discharge canal on April 18, 1972 at sampling site 4 (see Figure 5.4).

Listed in Table 5.32 are the net integrated count rates of the probe in the spectral range of 1.0 to 1.4 MeV, the ^{60}Co gamma-ray region. These were determined by subtracting the count rate of samples obtained in the Great Bay background area (mostly from radium and thorium daughters) from those of similar type samples collected from Barnegat Bay, Oyster Creek and Forked River. These net count rates are compared in Table 5.32 to the ^{60}Co content (pCi/g-dry weight) in concurrently collected sediment samples. The counting efficiency of the probe varied between 60 to 500 cpm per pCi/g, with an average of

Table 5.32 Net Count Rate of ^{60}Co with Underwater Probe and Measured ^{60}Co Concentrations in Related Sediment Samples

Sample No.	Probe, net count/min	Sediment Samples pCi/g	C/min per pCi/g
		Silty Samples	
5	500 ± 100	9.0	60
6	1100 ± 200	5.0	220
10	2100 ± 200	18.6	110
11	200 ± 50	1.2	170
12	2500 ± 200	5.0	500
13	800 ± 200	5.3	150
17	<50	0.1	---
18	<50	0.2	---
21	100 ± 30	0.6	170
22	<50	0.1	---
23	<50	0.1	---
25	100 ± 30	0.4	250
27	400 ± 50	1.6	250
31	<50	0.2	---
32	<50	0.1	---
34	200 ± 50	1.0	200
35	300 ± 50	1.7	180
		Sandy Samples	
19	<50	<0.1	---
20	<50	0.2	---
24	<50	<0.1	---
26	<50	0.1	---
33	<50	0.2	---
36	<50	<0.1	---

Notes:

1. Samples collected October 18-22, 1972.
2. Net count rate of probe for gamma rays with energies between 1.0 - 1.4 Mev; counting times were 10 min.
3. ± values are 2-sigma counting error; < values are 3-sigma counting error.
4. Concentration of ^{60}Co in dried sediment samples from Table 5.29.

210 ± 100 cpm per pCi/g. This is a lower efficiency than measured previously at other nuclear power stations.*(26,29)* Hence, the probe is not an appropriate tool for making quantitative analyses of sediments *in situ*, although it is useful as a surveillance technique for locating areas of radioactive buildup with a limiting sensitivity of about 0.5 pCi ^{60}Co/g.

Cobalt-60 was the principal radionuclide in sediments that indicated contamination from the station. It was detected in the bay as far north as Toms River, as far south as the Manahawkin Bridge, and in nearly all samples collected between these locations. Similar to the algae results, radioactivity in sediment samples collected near the west shore of the bay was generally higher than in samples from near the east shore. Cobalt-60 was also detected in a sample collected from Forked River above the South Branch, presumably deposited during high tides. No radioactivity attributable to the station was detected in sediment samples collected from the northern (near Point Pleasant) or southern (Little Egg Harbor) extremities of Barnegat Bay.

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6. ENVIRONMENTAL AIRBORNE ACTIVITY

6.1 Introduction

6.1.1 *Purpose.* Radiation exposures and radionuclide concentrations were measured in or beneath the plume from the stack to confirm the annual population radiation doses calculated by the station operator from radionuclide release data, meteorological dispersion models, and photon dose equations. Gaseous effluent from nuclear power stations with boiling-water reactors is the main source of radiation dose to the population.

Concentration measurements in the environment were compared with release rates determined at the same time in the stack or the main condenser steam jet air ejectors to obtain dispersion values under the atmospheric conditions prevailing during the brief measurement periods. Radiation exposure results were related to these release rates, and are intended for computing annual radiation doses by adjusting for annual average conditions of atmospheric stability, wind speed, and wind direction. To obtain net values, the radiation background was determined by repeating the measurement at each location after the wind direction had changed so that the plume was no longer near the location.

Brief (1/4 to 2 hours) ground level measurements were conducted at various locations beyond the station perimeter during different atmospheric conditions (see Section 6.2). Plume radiation was determined directly with sensitive ionization chambers. Radioactive gases were collected in tanks by pumps, particles by high-volume air samplers and filters, and radioiodines by air samplers and various types of filters and charcoal. An ionization chamber mounted aboard a helicopter provided measurements of the radiation fields and extent of the plume (Section 6.3). Measurements were also performed near the station to determine radiation being emitted directly from various on-site structures (Section 6.4). For longer periods (up to six weeks) sensitive thermoluminescent dosimeters were placed at many locations to measure long-term exposure (Section 6.5).

6.1.2 *Environment of Oyster Creek.* The station is located on a 573-hectare (1,416 acres) site in the eastern portion of the Pine Barrens of New Jersey. The site lies in Lacey and Ocean Townships in Ocean County. The plant is located 430 m west of U.S. Highway 9, which intersects the site. The Garden State Parkway bounds the site on the west. Undeveloped land lies beyond the north and south boundaries, consisting of the south branch of the Forked River and Oyster Creek, respectively. Residential developments surround the eastern portion of the site. The 1140-MWe Forked River pressurized-water reactor is being constructed on a site west of the plant. The local area, particularly to the west, is densely wooded with mostly pitch pines and some mixed hardwoods. The ground is sandy and relatively flat, sloping gradually from 3 m above mean sea level near the eastern shoreline to about 18 m at 3 km to the west. The north and east quadrants contain many waterways, lakes, and fresh and salt water marshes. Barnegat Bay lies about 3 km to the east and the Atlantic Ocean, 10 km.*(1)*

Land within 10 km of the station is poor for agriculture. Cranberries are cultivated in bogs about 10 km to the north. Virtually no milk is produced in the vicinity. Some milk-producing cattle were recently reported to be located 9 km south and a herd of four cows, 10.6 km northnorthwest. Goats are milked 14 km to the southwest.*(2)* Because of the poor crop and pasture conditions around the station, vegetables and milk were not collected.

Deer were present around the station. Since no radioactivity due to station effluents had been detected in specimens collected near other power reactors,*(3,4,5)* deer near Oyster Creek were not considered an important pathway to man and no samples were collected.

Based on the 1970 census, the station is located in a region of relatively low but increasing population density. The nearest communities are Forked River, about 2.5 km northeast, and Waretown, 2.5 km southeast. The largest nearby population (23,554) resides in Toms River and adjacent communities about 15 km north. The number of residents, particularly in regions adjacent to Barnegat Bay and water recreational areas, is expected to grow at a rate of 4 percent annually.*(2)* In addition to the permanent population, a sizeable influx of part-time residents occurs in the waterfront areas during summer months.

The 1970 resident population was:*(1)*

Distance from site, km	Accumulated population	Distance from site, km	Accumulated population
1.6	226	16	45,586
3.2	2,514	32	229,243
4.8	5,433	48	513,510
8.0	9,835	80	3,483,895

The resident and estimated seasonal population in various directions within 3.2 km of the site was:

	Population within 1.6 km		Population between 1.6 and 3.2 km	
Direction	Resident	Seasonal	Resident	Seasonal
N	0	0	198	381
NNE	75	153	333	644
NE	79	154	257	499
ENE	0	0	441	852
E	0	0	75	145
ESE	42	151	158	571
SE	28	101	305	1105
SSE	2	0	225	815
S	0	0	224	128
SSW	0	0	31	17
SW	0	0	41	23
WSW	0	0	0	0
W	0	0	0	0
WNW	0	0	0	0
NW	0	0	0	0
NNW	0	0	0	0
Total	226	559	2288	5180

6.1.3 *Meteorology.* The local climate is of a continental type modified by maritime effects.*(1)* Westerly winds prevail, blowing usually from SSW to NW. Northeasterly winds, however, occur frequently during precipitation. The proximity of large bodies of water induce onshore winds during warm, sunny periods. Annual rainfall averages 107 cm, with 8 to 13 cm occurring each month.

A 122-m-tall meteorological tower stands 360 m west of the effluent stack. Wind speed and direction are measured at 10, 23 and 122 m elevations and recorded continuously. Thermometers are located at 3.7, 23, 61 and 122 m and read every 15 min. The station operator determines atmospheric stability from the difference in temperature between 3.7 and 122 m. The meteorological data are summarized quarterly and annually by a contractor. The AEC has indicated, however, that the data collected at the tower up to 1974 are of doubtful accuracy and that an improved program is being implemented.*(2)* During this study, incorrect temperature and wind data were detected and corrected by results of balloon releases, compass sightings and other observations.

6.1.4 *Off-site surface air surveillance by the State.(6)* At the time of this study, the New Jersey State Department of Environmental Protection, Bureau of Radiation Protection (BRP), maintained a network of sampling stations for monitoring concentrations of radioactive particles and iodine in air in the vicinity of the Oyster Creek station. The network consisted of 5 stations within 12 km of the site and a background station 24 km west of the site. Each sampler, operated at a flow rate of 0.7 m^3/min, contained a particulate filter (Mine Safety Appliances Co. type BM-2133) and a charcoal canister (MSA part No. 46727, similar to type 2306). Samples were changed every 7 days, and analyzed by a Geiger-Muller beta-particle detector and a gamma-ray spectrometer with a Ge(Li) detector. Radioiodine on charcoal was analyzed with a Ge(Li) or NaI(Tl) detector coupled to a gamma-ray spectrometer. Radiostrontium was chemically separated from composited particulate filters and analyzed with a proportional counter.

Although most radioactivity on the air filters was attributed to fallout from nuclear weapons testing, quantities of ^{54}Mn, ^{60}Co and ^{131}I were definitely traceable to Oyster Creek. Cobalt-60 was the most frequently detected radionuclide. Measured ^{89}Sr and ^{90}Sr probably originated from fallout. BRP reported that most radioactive particles in air near Oyster Creek were 10^{-4} to 10^{-7} of the maximum permissible concentration values (10CFR20, Table 2, Column 1) for the various radionuclides.

Iodine-131 was frequently measured in the week-long samples, particularly those obtained 2 to 4 km from the Oyster Creek station. Up to the end of 1973, the highest measured concentration was 1.3×10^{-10} $\mu Ci/m^3$, which occurred during the period after reactor startup on January 10, 1973. Elevated ^{131}I airborne concentrations on the order of 1×10^{-11} to 6×10^{-11} $\mu Ci/m^3$ were measured during the two-month period before shutdown for refueling in April 1973. BRP indicated that most ^{131}I measured in air was in the form of methyl iodide.

6.2 Short-Term Ground-level Radiation Exposure Rates and Radionuclide Concentrations.

6.2.1 *Exposure measurements.* Radiation exposure was measured during the first two field trips with a sensitive muscle-equivalent ionization chamber and

Shonka electrometer, from which exposure data are obtained by measuring the time required to null a one-volt charge placed on the chamber.*(7,8)* The measurement is made by observing the movement of a fiber in the electrometer through a microscope. After the second field trip, the system was modified with a Keithley electrometer and a strip-chart recorder to record either continuous or integral exposure readings. The system was calibrated with a radium standard to convert readings to microroentgens per hour (µR/hr).

Also utilized were cylindrical NaI(Tl) gamma-ray detectors (5- x 5-cm) connected to portable count-rate meters. The instruments had been calibrated by comparing their count rates for gamma rays in the natural radiation background at Cincinnati with measurements by the muscle-equivalent ionization chamber. Radiation levels during calibration ranged from 5 µR/hr over water in a lake to 19 µR/hr over granite. The count rate (C, counts/min) of the survey instruments varied linearly with the radiation exposure rate (R, µR/hr) of the ionization chamber; a typical calibration curve had the equation $R = 7.0 \times 10^{-4}C + 3.3$. Radiation exposure rates at measurement locations near Oyster Creek not affected by the plume were computed by applying these calibration curves to the observed count rates.

Despite the dependence of the counting efficiency of NaI(Tl) detectors on the energy distribution of the gamma-ray flux, the calibration curves have been found applicable in a variety of natural radiation backgrounds. In numerous measurements, the standard error of the survey meters was ± 0.35 µR/hr, and the exposure values computed from the readings were within 4 percent of the values measured with the ionization chamber in 95 percent of the measurements.*(9)*

For measurements under the plume, where the gamma-ray energy distribution differed greatly from natural background, the portable instruments were calibrated by comparing their count rates with measurements by the muscle-equivalent ionization chamber. Again, the count rate was found to vary linearly with radiation exposure rate, although the relationship was different than for natural background.

During the fifth field trip, a pressurized ionization chamber (PIC)*(10)* was tested in comparison with the muscle-equivalent ionization chamber. The PIC consists of a high-pressure, argon-filled steel chamber, an electrometer, a recorder and a power supply. The instrument was calibrated with a radium standard to convert readings to µR/hr.

6.2.2 *Concentration measurements.* Gaseous samples were obtained with an air compressor (27-V DC Cornelius model 32-R-300) connected to a 34-liter low-pressure gas bottle rated to contain 0.9 m^3 at maximum pressure. Each cylinder was filled with about 0.4 m^3 air. The pump was powered by an 115-V AC motor generator with output converted to 27 V DC by a full-wave rectifier.

For ^{133}Xe analysis, sampled air was released at the laboratory from the tank at a rate of 6 liters/min for 16.7 min. It was passed through beds of Linde 13X molecular sieve and Ascarite for removal of water vapor and CO_2, then through a 1-cm-dia x 80-cm copper cooling coil, and finally through a 3.2-cm-dia x 66-cm copper U-tube containing 180 g of Columbia 6GC (10–20 mesh) charcoal. Both tubes were immersed in a -76° C dry-ice-acetone refrigerant bath. The charcoal under these conditions collected all ^{133}Xe from one m^3 or less of air.

After passage of 100 liters, the U-tube was opened and the charcoal transferred to 10-cm-dia, 450-cc plastic containers. The charcoal was allowed to warm up for one hour to room temperature to eliminate pressure build-up. The container was then sealed with a rubber gasket and a bolted lid. Thirty-five percent of the ^{133}Xe on the charcoal is lost due to warming. The charcoal was analyzed for 1000 min with a 10- x 10-cm NaI(Tl) gamma-ray detector connected to a 200-channel spectrometer. The analyzer was calibrated with a ^{133}Xe radioactivity standard from the National Bureau of Standards.

The remainder of the air sample was analyzed for ^{85}Kr, adding 1.86-hr ^{83m}Kr to determine the krypton yield. Krypton was separated and purified by cryogenic fractionation.*(11)* The fraction was transferred to 25-cc bottles containing 15 cc of 1-mm-dia plastic scintillator spheres for analysis by a liquid scintillation counter.

Radioactive particles were sampled by pumping air at the rate of 1.5 m^3/min through a glass fiber filter (Mine Safety Appliances type 1106, 20 x 26 cm) with conventional high-volume air samplers. The filters were counted within approximately 30 min with NaI(Tl) gamma-ray spectrometers* to detect short-lived ^{88}Rb and ^{138}Cs, the progeny of the short-lived radioactive noble gas fission products, ^{88}Kr and ^{138}Cs, respectively.

Gaseous radioiodines were sampled by pumping air through a 96-g bed of activated charcoal (MSA cartridge type 2306) mounted with holding rings and a gasket on a high-volume air sampler. Also, to sample gaseous radioiodine, glass fiber filters impregnated with sodium thiosulfate were placed behind the filter for particle sampling. Organic species of iodine were sampled with 96-g cartridges of KI-impregnated charcoal (MSA charcoal type 85851). The media were analyzed with NaI(Tl) or Ge(Li) detectors and gamma-ray spectrometers for periods of 100 or 1000 min.

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*We thank Messrs. David McCurdy, N.J. Department of Environmental Protection, and Harold Beck, HASL, AEC, for counting these samples.

6.2.3 *Description of tests.* Five sets of tests were conducted in the environs of Oyster Creek from January 1972 to April 1973. Most measurements were made at ground level within 5 km of the stack. Radiation exposure and airborne concentrations were frequently determined simultaneously. For air sampling, slightly unstable to neutral atmospheric conditions were selected since the plume was likely to be at ground level at relatively short distances.

Test locations, atmospheric conditions and types of measurements and samples obtained are summarized in Table 6.1. Sampling locations of tests 1 through 4 are indicated on Figure 6.1 and, of the fifth test, on Figure 6.11. Wind directions and speeds at the top of the stack are from the station meteorological tower. Independent observations of wind direction were also made by a meteorologist by releasing balloons. Atmospheric stability conditions frequently had to be determined by the meteorologist on the basis of professional judgment, because some meteorological tower data — particularly temperature differences as a function of elevation — were found to be in error.*

After 0900 hrs on January 18, 1972, the atmosphere was initially slightly unstable, changing to neutral, marked by a decrease in wind speed and a shift in wind direction. The intent of the test 1b during the evening of that day was to measure the plume under very stable (inversion) conditions with the plume aloft. This condition had not been reached, however, at the time of measurement. Test 1c was undertaken in the morning of January 19 under cloud cover with somewhat changeable winds and occasional light rain. The stack radioactivity release rate was 3.6×10^4 µCi/s on both days.

The weather during test 2a on April 11, 1972, was overcast with low, thick clouds. The wind speed decreased gradually during sampling and heavy rain began at 0935 hrs. During test 2b, the sky was partly cloudy with fluctuating wind direction. The stack radioactivity release rate at this time was 7.8×10^4 µCi/s.

On August 22 and 23, 1972, the plume was measured on several occasions to test the muscle-equivalent ionization chamber and Keithley electrometer and to determine exposure levels on the highway in front of the station when the plume was moving both overhead and away. During this time the surface wind due to the pressure gradient was generally from the south, but the presence of the ocean nearby produced east winds from the ocean during the day, and west winds toward the ocean at night. The days were sunny and hot. In the morning of August 23, the direction trace at 122 m was steady until 0810 and shifted from then on, indicating less stable air. The early morning was foggy. The release rate of noble gas fission products was reported by the station to be 1.4×10^4 µCi/s.

During the December 1972 trip, gas and particulate samples were collected in the plume; radiation was measured on and off the reactor site with a NaI(Tl) detector and a spectrometer, NaI(Tl) survey meters, and a muscle-equivalent ionization chamber. The on-site measurements provided data on radiation being emitted from station buildings. The Ludlum survey meters with NaI(Tl) detectors were a new type, tested in the field for the first time. The stack radioactivity release rate during the period was 4.0×10^4 µCi/s. The skies were cloudy on December 12 with the temperature rising slowly throughout the day. December 13 was cloudy and windy. The temperature continued to rise until noon, then began falling after the winds shifted due to a passing cold front. Skies were mostly cloudy with weak sunshine during midday of December 14. The winds were regularly shifting between NNE and ENE. After 1240 hrs, the general wind direction was northerly with continuous shifting.

The purposes of the April 1973 trip were 1) to compare response from a high-pressure ionization chamber with a muscle-equivalent ionization chamber while in the plume at ground level, and 2) to attempt to measure the radiation field of the plume by mounting a muscle-equivalent ionization chamber in a helicopter and making traverses at various distances from the stack. The latter was conducted on the afternoon of April 3 (test 5c) and the morning of April 4 (test 5d). The stack radioactivity release rate during the period was 1.39×10^5 µCi/s. The morning of April 3 was sunny

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* We thank Messrs. P. Humphrey, G. DeMarrais, and R. Fankhauser, Division of Meteorology, EPA, NERC-RTP, for participating in the field trips and undertaking the meteorological analyses.

Table 6.1 Conditions for Radiation Dose Measurements of Stack Effluent in the Environment

Test No.	Date	Period, hrs	Sampling point azimuth, deg.	Distance from stack, km	Atmospheric stability class*	Mean wind direction,** deg.	Mean speed,** m/s	Types of measurement+
1a	Jan. 18, 1972	0930-1030	72	2.4	D	255	5.6	R,P
1b	Jan. 18, 1972	2000-2100	35	2.1	E	235	10.6	R,P
1c	Jan. 19, 1972	0845-1015	60	1.7	D	260	8.8	R,G,P
2a	Apr. 11, 1972	0900-0930++	0	2.4	D	180	6.0	R,P,I
2b	Apr. 11, 1972	1500-1615	135	1.6	D	180	8.4	R,G,I
3a	Aug. 22, 1972	1730-1900	22-127	0.4-0.8	D	180	5.0	R
3b	Aug. 23, 1972	0700-0800	22-127	0.4-0.8	E-F	260	5.2	R
3c	Aug. 23, 1972	0820-0910	85	0.35	D-E	260	2.4	R
4a	Dec. 12, 1972	1400-1630	22-127	0.4-0.8	D-E	80	4.6	R
4b	Dec. 13, 1972	0950-1215	270	0.2-0.4	D	250	10.0	R,S
4c	Dec. 13, 1972	1540-1735	127	0.6	D	300	11.0	R,S
4d	Dec. 14, 1972	1130-1340	239	3.9	D	50	5.3	R,G,P,I
5a	Apr. 3, 1973	0930-1000	100	1.5	C	280	7.4	R,G,I
5b	Apr. 3, 1973	1000-1200	100	1.5	D	275	7.3	R,I
5c	Apr. 3, 1973	1515-1545	100	1.5,10	D,D-C	210-290	6.2	R
5d	Apr. 4, 1973	0815-1030	285	0.8-34	D	85-105	4.5-9.8	R

* Pasquill-Gifford atmospheric stability classification:

A - extremely unstable	D - neutral
B - moderately unstable	E - slightly stable
C - slightly unstable	F - moderately stable

**Measured at the 122-m elevation on the meteorological tower.

+ Code: G - gas sampling; I - radioiodine sampling; P - particle sampling; R - radiation exposure; S - gamma-ray spectrometry.

++No meteorological observations after 0930.

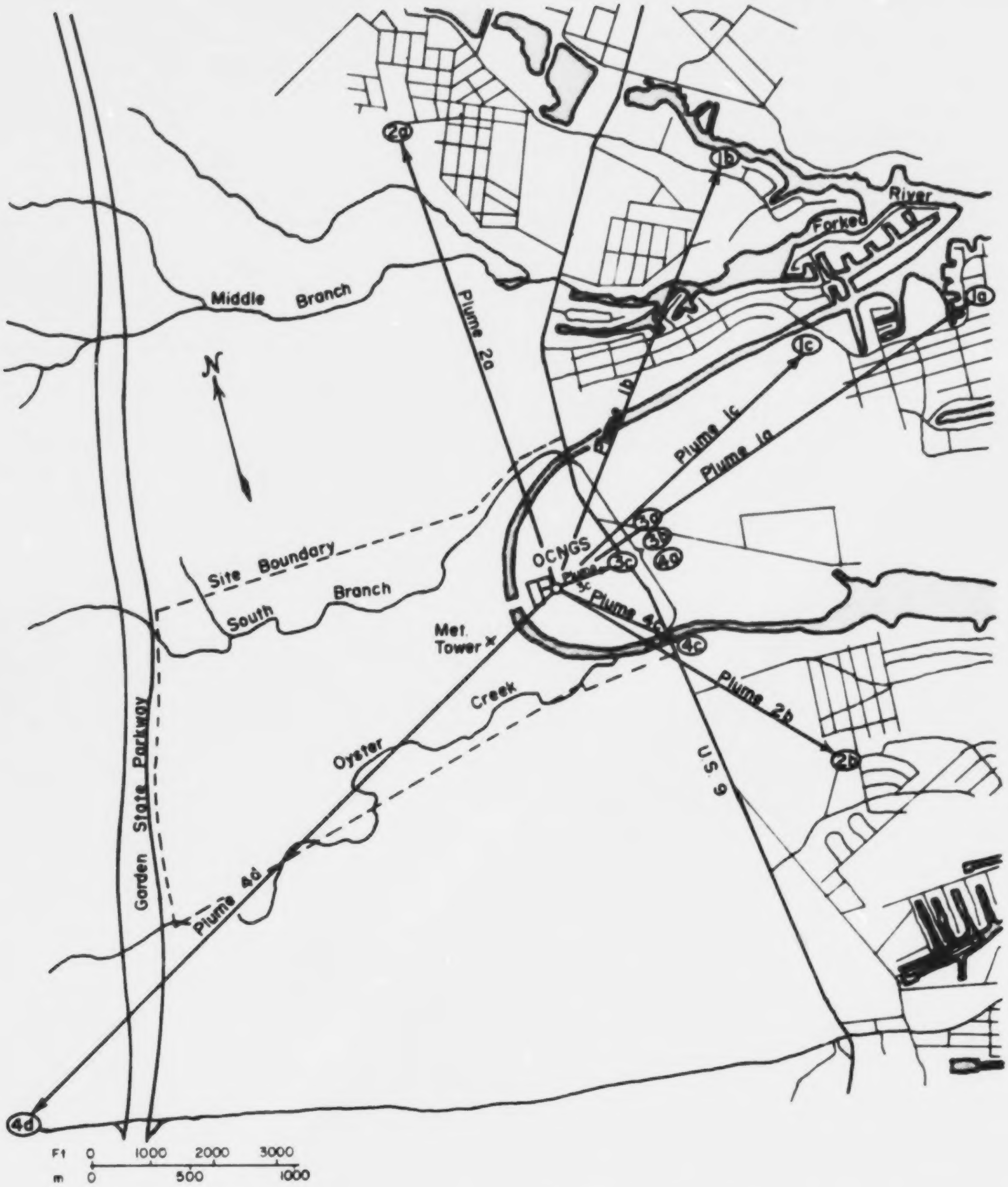
2a
1b
Forked
River
1a
1c
Middle Branch
N
Plume 2a
Plume 1b
Plume 1c
Plume 1a
3a
3b
4a
OCNGS
3c
Plume
Plume 4c
4c
Site Boundary
South Branch
Met. Tower
Oyster Creek
Plume 2b
2b
U.S. 9
Garden State Parkway
Plume 4d
4d
Ft 0 1000 2000 3000
m 0 500 1000

Figure 6.1 Sampling locations for environmental radiation measurements.

with westerly winds. Clouds began developing after 0930 hours. An hour later, the sky was overcast, with intermittent breaks. Light rain occurred after 1130. Cloudiness slowly diminished during the afternoon so that by 1530 hours cloud coverage was less than 50 percent. On the morning of April 4, a storm system approaching from the southwest caused eastsoutheasterly winds that changed slowly to easterly. The sky remained overcast after 0800 hours and neutral conditions persisted. Light rain started at 1030 hours.

6.2.4 *Estimated atmospheric dispersion.* Atmospheric dispersion along the plume centerline at ground-level downwind sampling locations was estimated by the Pasquill-Gifford model.*(12)* The dispersion equation and coefficient values for the various sampling tests are given in Appendix E.4. The vertical and horizontal plume dispersion values apply to the atmospheric stability class judged to be prevailing. The model was derived for open and level terrain and for 10-min sampling intervals. Measurements were adjusted to account for plume meander when sampling periods exceeded 10 min.*(12)* Plume rise estimates based on the techniques of Briggs*(13)* were computed by the USEPA Meteorology Laboratory for various ambient air temperatures, stability classes and wind speeds.*(14)* Xenon-133 test data, dispersion values indicated by measured ^{133}Xe concentrations or predicted by the model, and exposure rates from plume radioactivity are given in Table 6.2. Exposure rates, discussed in Section 6.2.6, represent the mean of 10-min measurements with the muscle-equivalent ionization chamber during the ^{133}Xe sampling periods.

6.2.5 *Air sampling results.* Xenon-133 was observed in most samples of air analyzed for radioactive gases as shown in Table 6.2. No other gaseous radionuclides with half-lives of less than 5 days were measured because either the interval between sampling and laboratory analysis was too long or stack emission rates lead to unmeasurable ambient concentrations. Krypton-85 was detected only in one sample (test 2b); it could not be measured at other times because of relatively low emission rates or insufficient sample quantities for analysis.

Atmospheric dispersion (χ/Q) values were obtained by dividing measured ^{133}Xe concentrations in ground-level air by the ^{133}Xe stack release rate (see Section 3.3.6). The values agreed within a factor of two with values for the plume centerline calculated by the Pasquill-Gifford technique only in test 5a. Although this sampling interval was the shortest, it occurred when the release rate was relatively high, which may have aided in defining the optimum sampling location. Other measured χ/Q values exceeded predicted levels based on neutral (category D) atmospheric stability by factors ranging from 3 to 32. Using an alternative atmospheric condition (slightly unstable, category C), predicted χ/Q values become 8.1 x 10^{-7} s/m^3 for tests 1c and 9.6 x 10^{-7} s/m^3 for test 2b. Measured values then agree closely for test 1c and within a factor of 3 for test 2b.

No ^{133}Xe was detected in test 4d although the predicted χ/Q value exceeds by a factor of 4 that given by the minimum detectable concentration level. The relatively low average radiation exposure rate of 2.8 µR/hr indicates that the air sampler may have been located frequently on the fringe of the plume, where the ^{133}Xe concentration is lowest.

The measured ground-level ^{85}Kr concentration during test 2b was 2.8 ± 0.1 x 10^{-4} µCi/m^3 when the stack release rate was 9.4 µCi/s, as measured the previous day. The resulting measured χ/Q value is 340 and 30 times greater than levels predicted for category D and C stabilities, respectively. A possible explanation for these large discrepancies may be a significant increase in the stack release rate during sampling.

The progeny of ^{88}Kr and ^{138}Xe plume constituents, 17.8-min ^{88}Rb and 32.2-min ^{138}Cs, respectively, were observed on a glass fiber particulate filter exposed during all of test 1c. On this occasion, the New Jersey State mobile laboratory with a NaI(Tl) gamma-ray spectrometry system provided analysis immediately after sampling. A sample volume of 133 m^3 of air was obtained from 0857 to 1014 hrs and the filter was analyzed for 30 min. Krypton-88 and ^{138}Xe were being discharged at 4630 and 1840 µCi/s, respectively, according to measurements by the AEC Health and Safety Laboratory.*(15)* Estimated ambient levels of the progeny were based on ingrowth beginning after passage through the off-gas holdup line filters and a 3-min interval to reach the sampling location (^{88}Rb and ^{138}Cs levels were corrected for decay that occurred during samling and analysis). The effective release rates (Q) were computed to be 510 µCi/s of ^{88}Rb and 115 µCi/s of ^{138}Cs. Measured ambient concentrations were 2,000 ± 400 pCi/m^3 of ^{88}Rb and 150 ± 20 pCi/m^3 of ^{138}Cs. Using the predicted dispersion value of 1.1 x 10^{-7} s/m^3 (see Table 6.2), ambient concentrations were expected to be 57 pCi/m^3 of ^{88}Rb and 13 pCi/m^3 of ^{138}Cs, which are 35 and 12 times less than the measured values. As with ^{133}Xe, use of the alternative dispersion value of 8.1 x 10^{-7} s/m^3 for slightly unstable conditions leads to predicted concentrations that are factors of 5 and 2 less than measured levels. In addition, as shown by the radiation exposure rates in Figure 6.4, the plume

Table 6.2 Xenon-133 in Environmental Air Samples

	Test No.					
	1c(1)	1c(2)	2b	4d(1)	4d(2)	5a
Sampling period, hrs	0850-0926	0929-1014	1512-1610	1153-1230	1231-1317	0945-1000
Sample volume, m^3	0.33	0.36	0.40	0.22	0.40	0.084
Stack release rate, μCi/s	7,900	7,900	11,200	3,400	3,400	22,240
Measured concentration,* μCi/m^3	$2.8 \pm 0.2 \times 10^{-3}$	$8.7 \pm 0.1 \times 10^{-3}$	$3.1 \pm 0.1 \times 10^{-2}$	$< 4 \times 10^{-4}$	$< 4 \times 10^{-4}$	$2.1 \pm 0.2 \times 10^{-2}$
Atmospheric dispersion (χ/Q), s/m^3						
Measured	3.5×10^{-7}	1.1×10^{-6}	2.8×10^{-6}	$< 1.2 \times 10^{-7}$	$< 1.2 \times 10^{-7}$	9.3×10^{-7}
Predicted	1.1×10^{-7}	1.1×10^{-7}	8.8×10^{-8}	4.5×10^{-7}	4.5×10^{-7}	9.3×10^{-7}
Radiation exposure rate, μR/hr	14 ± 4	24 ± 4	11 ± 8	3.4 ± 0.8	2.3 ± 1.1	31 ± 20

*Normalized to 10-min sampling intervals.

Notes:

1. ± values for concentration data indicate analytical error expressed at 2-sigma and for exposure rates represent standard deviation of 10-min average results.
2. < values are minimum detectable concentrations at 3-sigma counting error.

occurred more frequently near the sampling location during the latter part of the test. In this event, measured concentration values would be lower and approximate the alternative predicted levels. Sampling for shorter intervals would be necessary for confirmation.

Particulate or gaseous iodine radionuclides were never observed in the atmosphere during brief sampling periods, primarily because the stack release rates lead to ambient concentrations below analytical sensitivity levels. For ^{131}I, the minimum detection levels for various sampling devices and expected concentrations during each optimum test of a sampling device were as follows:

Sampling device	Test no.	Sample volume, m^3	MDC,* µCi/m^3	Expected conc.,** µCi/m^3
Glass fiber filter	1c	133	< 3.8 x 10[illegible]	2.4 x 10[illegible]
Activated charcoal	5b	119	< 2.4 x 10[illegible]	2.0 x 10[illegible]
$Na_2S_2O_3$-coated filter	5b	210	< 2.6 x 10[illegible]	2.0 x 10[illegible]
KI-impregnated charcoal	2b	38	< 2.4 x 10[illegible]	2.2 x 10[illegible]

* Minimum detectable concentration at the 3σ confidence level.

**Assumes all effluent ^{131}I existed as the species being sampled.

6.2.6 *Exposure rate results.* Short-term exposure rate measurements were used to (1) determine the location of the plume for more detailed radionuclide concentration measurements, (2) confirm annual population dose estimates from calculation models using radionuclide release rates, meteorological dispersion models and photon dose equations, (3) calibrate portable survey meters for use in monitoring plume exposure rates and (4) to test new exposure rate measurement equipment.

On January 18 and 19, 1972, the plume from the stack was measured at the locations described in Table 6.1 and shown on Figure 6.1. The measured radiation exposure at location 1a at a total noble gas release rate of 3.6×10^4 µCi/s is shown in Figure 6.2. Radiation exposures during test 1b are shown in Figure 6.3. Test 1c was undertaken in the morning under cloud cover with somewhat changeable winds and occasional light rain. The radiation exposures during the period, shown in Figure 6.4, show a gradual increase from 9 to 25 µR/hr, with frequent fluctuations due to variations in wind direction. The bars on Figures 6.2, 6.3 and 6.4 indicate muscle equivalent ionization chamber measurement periods.

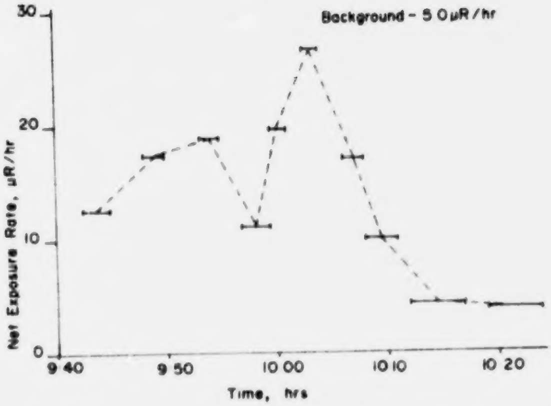

Figure 6.2 Net exposure rate in test 1a, January 18, 1972.

The plume was measured at two locations on April 11, 1972. The net radiation exposure for test 2a was approximately 9 µR/hr between 0908 and 0936 hours, and then dropped almost to zero when rain began (see Figure 6.5). For test 2b, periodic fluctuations in wind direction are indicated by the variations in radiation exposure shown in Figure 6.6, in the range 1 to 38 µR/hr.

The plume was measured on August 22 and 23, 1972, under the conditions shown for tests 3a and 3b in Table 6.1. The measured radiation exposure profiles, shown in Figure 6.7, are not instantaneous, because of the time required to traverse the distance of 0.8 km on the road, but no significant wind shift occurred during the measurements. On August 22 during test 3a, the plume was approximately parallel to the road; the higher value 0.35 km north of the stack is believed to be due to the spreading of the plume. Note that these are gross values. Net radiation exposure rates from the plume would be 4 to 6 µR/hr lower — the typical natural background rate in this area, which may also include some direct radiation from the station.

The constancy of the radiation exposure rate under the stable condition that prevailed in test 3b is suggested by the values shown in Figure 6.8 for the period immediately afterward (0820 to 0850), when the measurement for test [illegible] was made just east of the stack on Route 9. During test 3c, the plume crossed the road at right angles, resulting in a maximum radiation exposure rate of 10.5 µR/hr at the centerline under stable conditions, 12.5 µR/hr as the inversion gradually broke up, and peaking to 24 µR/hr as shown in Figure 6.8 during the transitory neutral condition.

Results of exposure rate measurements during test 4c with the muscle-equivalent chamber are shown in Figure 6.9. Measurements made over the same period

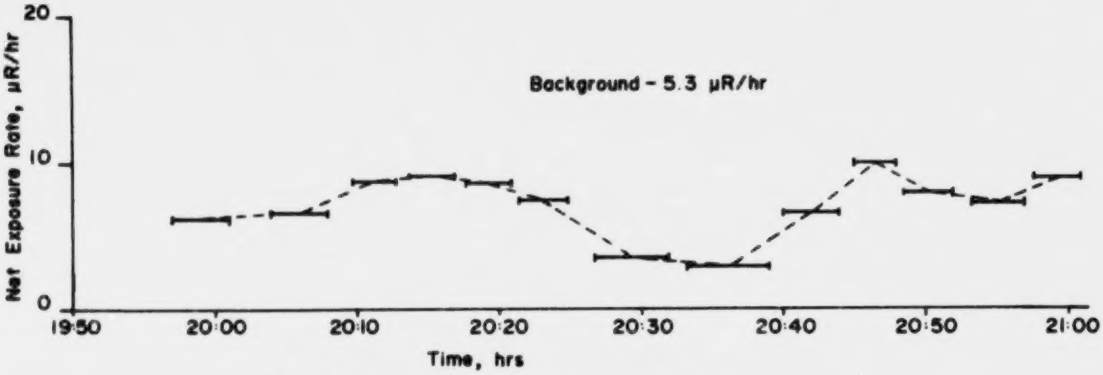

Figure 6.3 Net exposure rate in test 1b, January 18, 1972.

with the NaI(Tl) survey meters indicate that the survey meter calibration curve due to exposure to radionuclides in the plume can be represented by R = 2.8×10^{4} C, where R is the exposure rate above natural background in μR/hr and C is the survey meter count rate in counts/min.

Measurements in test 4d were made at distances of 3.9 and 9.0 km from the stack. Exposure rates measured at the 3.9 km location with the muscle-equivalent ionization chamber (see Figure 6.10) indicate that the exposure rate measured by the survey meter due to radionuclides in the plume can be represented by R = 3.5×10^{4} C. This relationship was found to hold above the natural background exposure rate of 4.1 μR/hr at that location. The average exposure rate above background during the sampling period was found to be 2.5 ± 1.7 μR/hr. The measurements made at a location 9 km from the stack, approximately 30 min later, yielded a net exposure rate of 2.3 ± 0.8 μR/hr.

During test 5b, plume radiation measurements were made simultaneously at distances of 1.5 and 10 km east of the stack, at the locations shown in Figure 6.11 (see Section 6.3.2). At the 1.5-km distance, continuous readings were obtained with the muscle-equivalent ionization chamber, and the values were

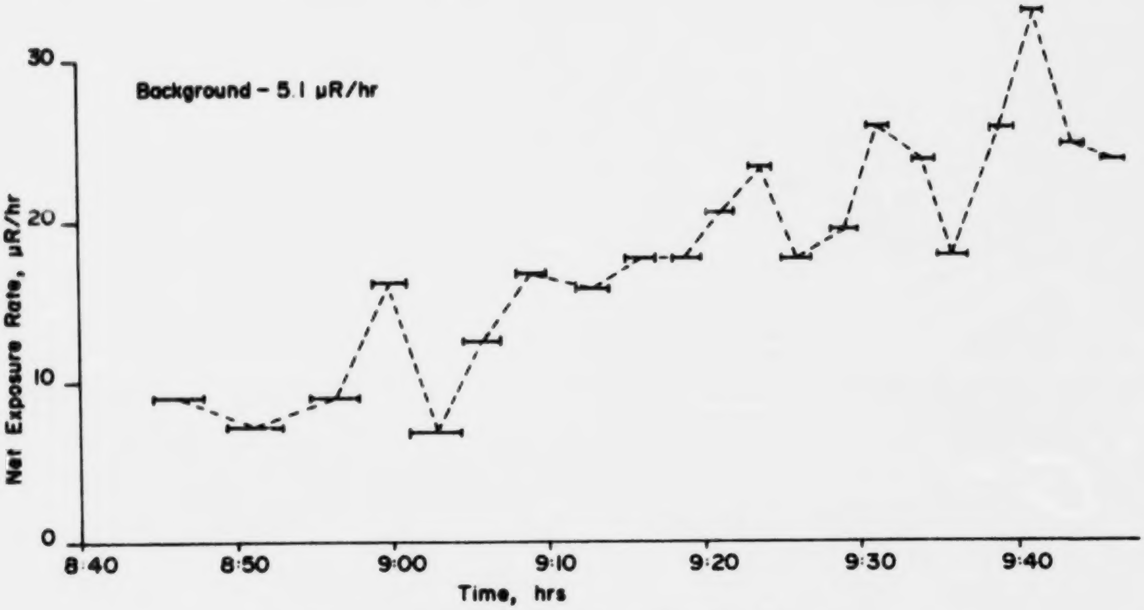

Figure 6.4 Net exposure rate in test 1c, January 19, 1972.

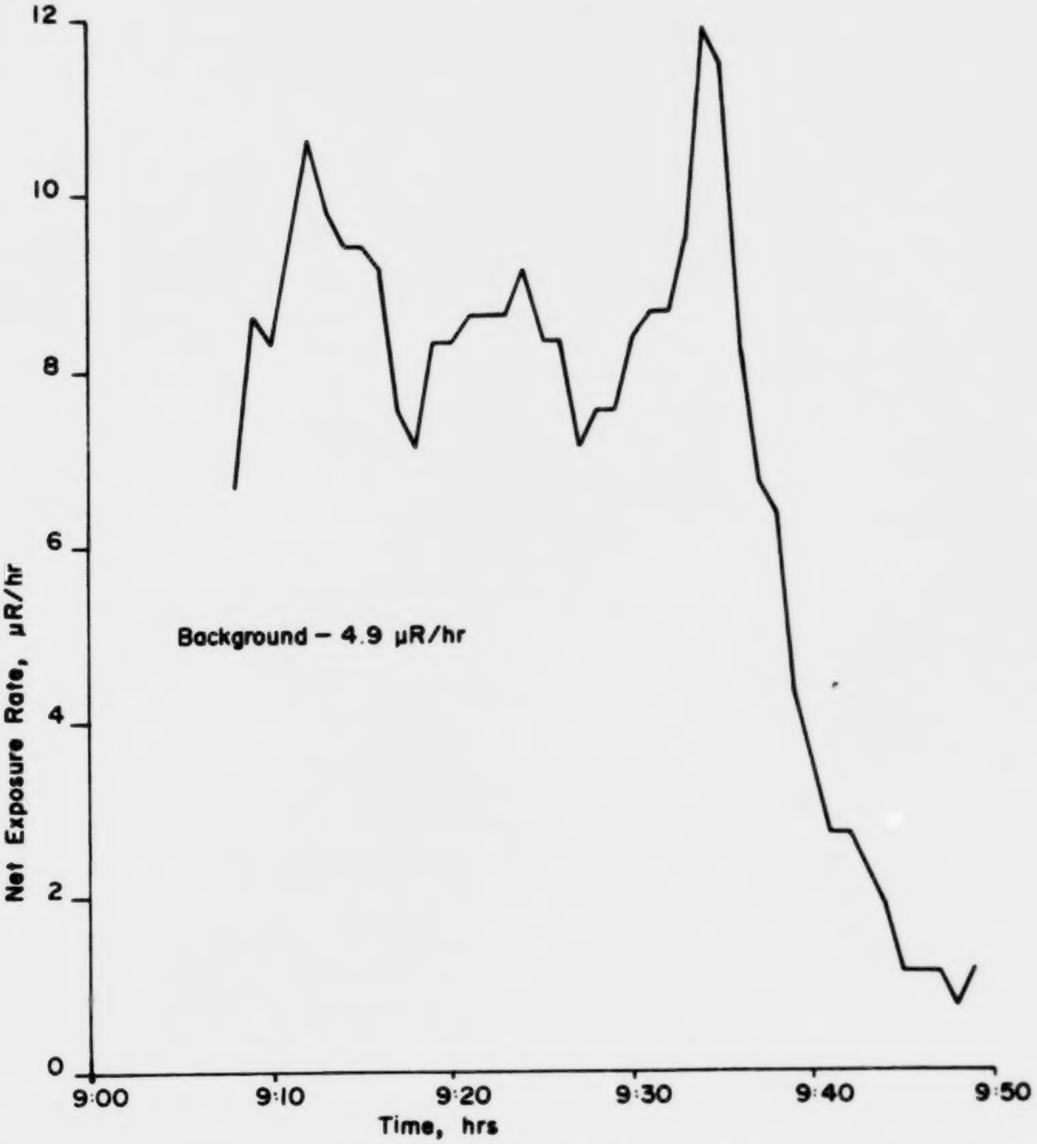

Figure 6.5 Net exposure rate in test 2a, April 11, 1972.

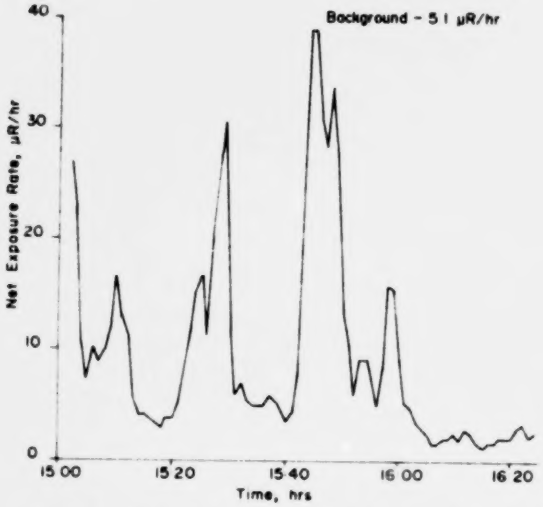

Figure 6.6 Net exposure rate in test 2b, April 11, 1972.

confirmed with a pressurized ionization chamber. Two survey meters with 5- x 5-cm NaI(Tl) detectors were calibrated for plume measurements relative to the muscle-equivalent chamber during part of this time. The exposure rate measurements at 10 km were conducted for 11 min in the Island Beach State Park east of Barnegat Bay with the same meters.

Ground-level measurements during test 5b, and during the airborne measurements of tests 5c and 5d (see Section 6.3), were compared to exposure rates computed by Gamertsfelder's treatment of a finite cloud, using his Eq. 7.43.*(16)* Standard deviation values were selected for either C or D stability conditions. The plume standard deviations in Figures 3.10 and 3.12 of Reference 16 were considered to be for approximately 10-min periods. The computed exposure was divided by the factor 1.4 for the longer period of measurement on the ground.*(12)* The plume rise was computed to be 28 m during test 5b.*(14)*

The average energy, $\bar{E}$, of gamma rays from the gas was computed to be 0.73 ± 0.03 MeV at 0, 4, 10 and 60 min after discharge. The composition of these radioactive gases at discharge, measured March 28, 1973, was:*(17)*

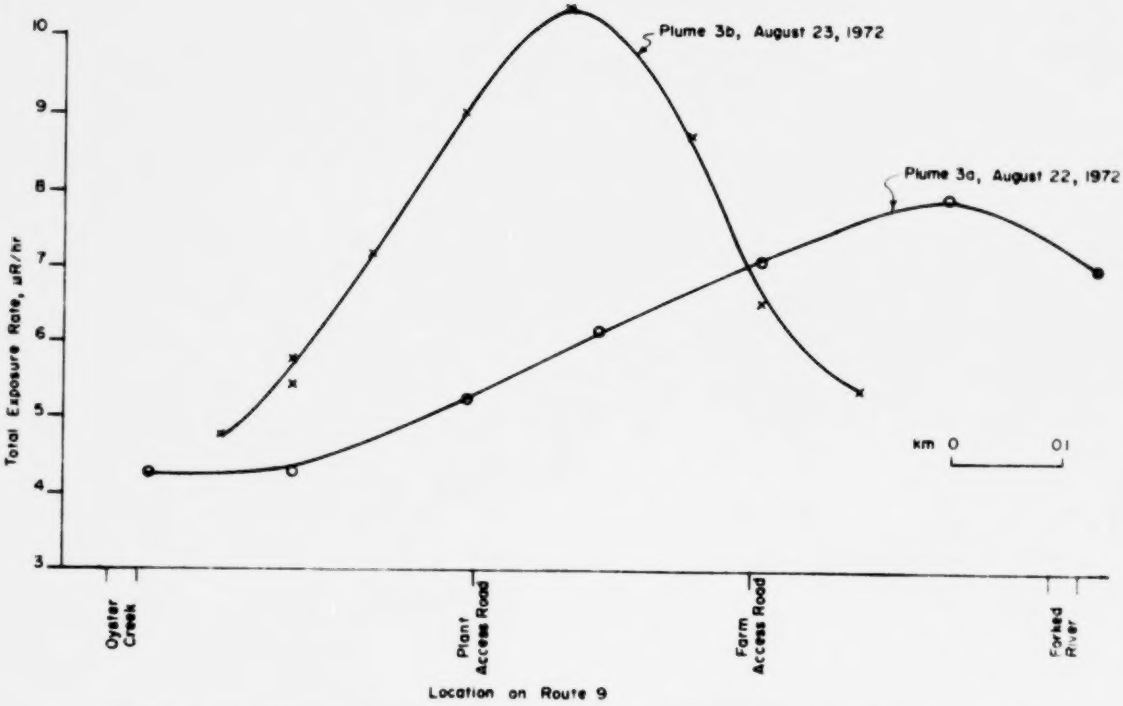

Figure 6.7 Gross exposure rate profile east of Oyster Creek Nuclear Generating Station during stable plume conditions.

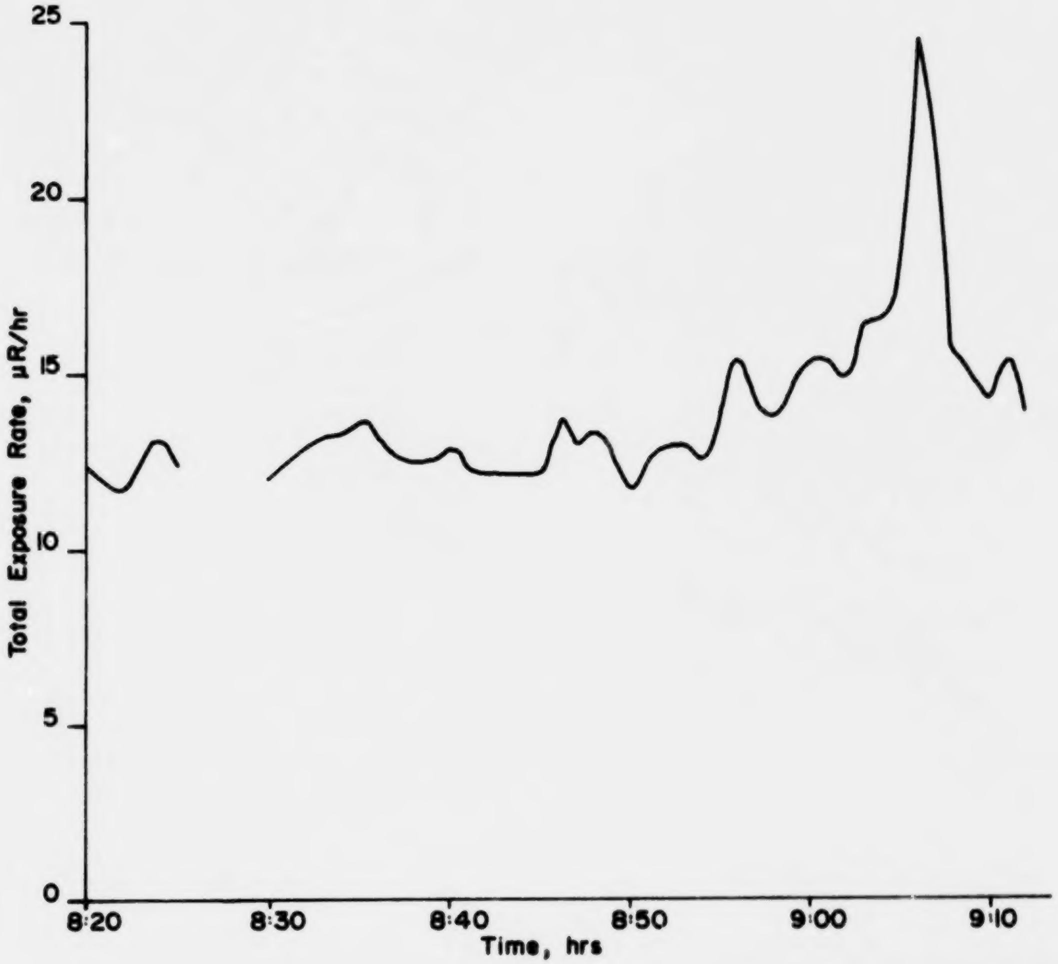

Figure 6.8 Gross exposure rate measurements in plume during change from stable to unstable meteorological conditions, test 3c, August 23, 1972.

Radionuclide		Stack effluent composition
4.48-hr	^{85m}Kr	0.071
76.3 -min	^{87}Kr	0.129
2.8 -hr	^{88}Kr	0.185
5.29-d	^{133}Xe	0.161
15.6 -min	^{135m}Kr	0.040
9.15-hr	^{135}Xe	0.348
14.2 -min	^{138}Xe	0.060

In addition to gamma rays from these radionuclides, those from 17.8-min ^{88}Rb and 32.2-min ^{138}Cs, formed by the decay of their radioactive precursors, were included in computing $\bar{E}$. The composition of this mixture approximated the average observed mixture (see Section 3.3.1) except that the ^{88}Kr value above is 25 percent higher and ^{135m}Xe is lower by a factor of two. The average radiation exposure rate above the natural radiation background was 32 µR/hr during a 144-min period 1.5 km east of the stack, and 2 µR/hr during an 11-min period 10 km east of the stack (see Table 6.3). The extensive fluctuation of the exposure rate is indicated by the 1-min averages at the 1.5-km location shown in Figure 6.12. Instantaneous values, those recorded at the instrument response time of 10 s, ranged from 2 to 162 µR/hr, and 10-min averages from 7 to 63 µR/hr. No difference is apparent in Figure 6.12 between the values before 1000 hours, when the sky was becoming cloudy (unstable, class C) and after 1000 hours, when the sky was overcast (neutral, class D).

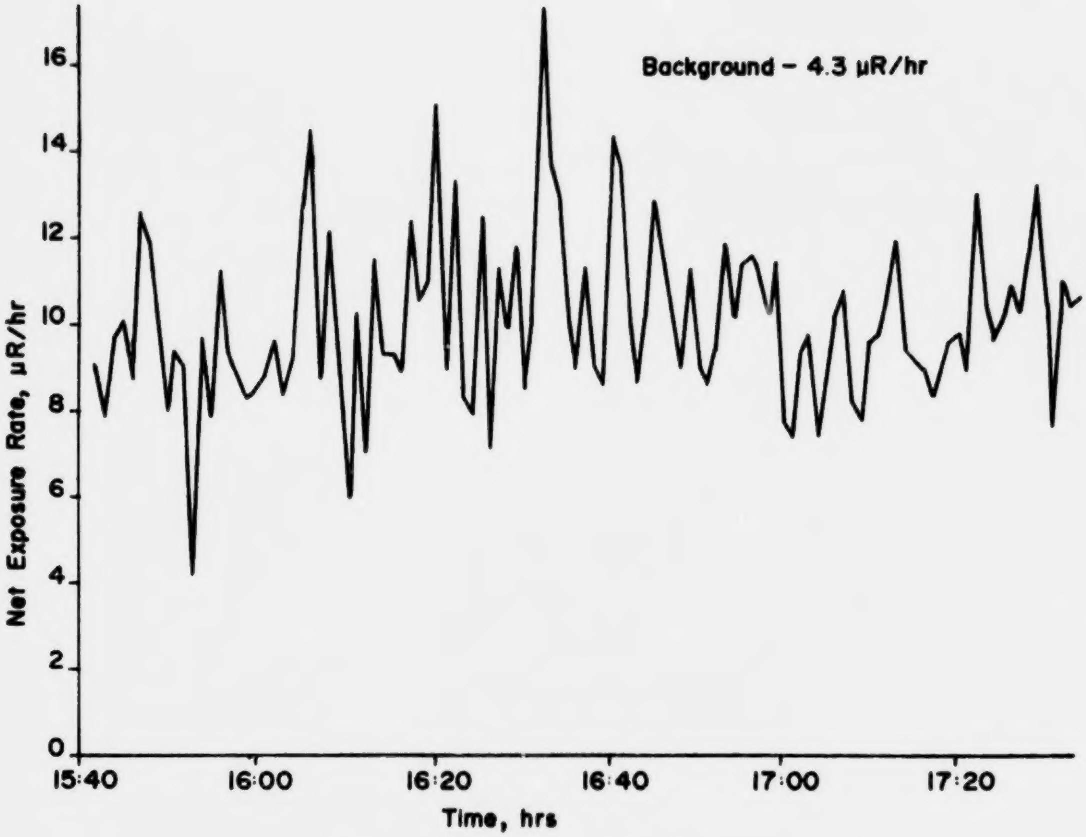

Figure 6.9 Net exposure rate in test 4c, December 13, 1972.

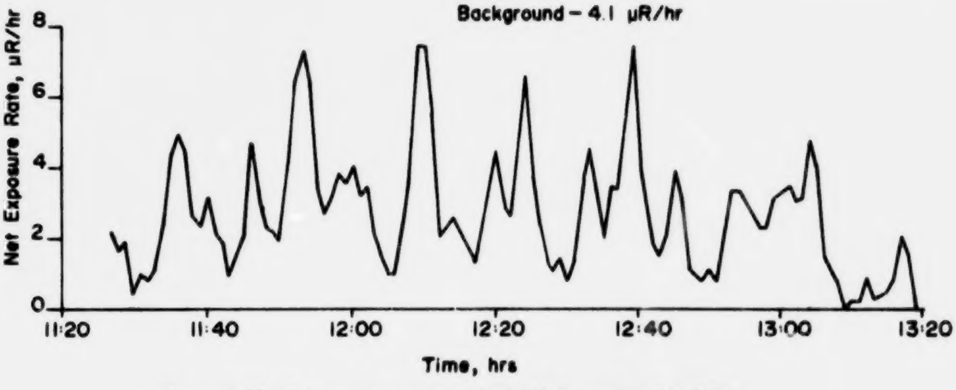

Figure 6.10 Net exposure rate in test 4d, December 14, 1972.

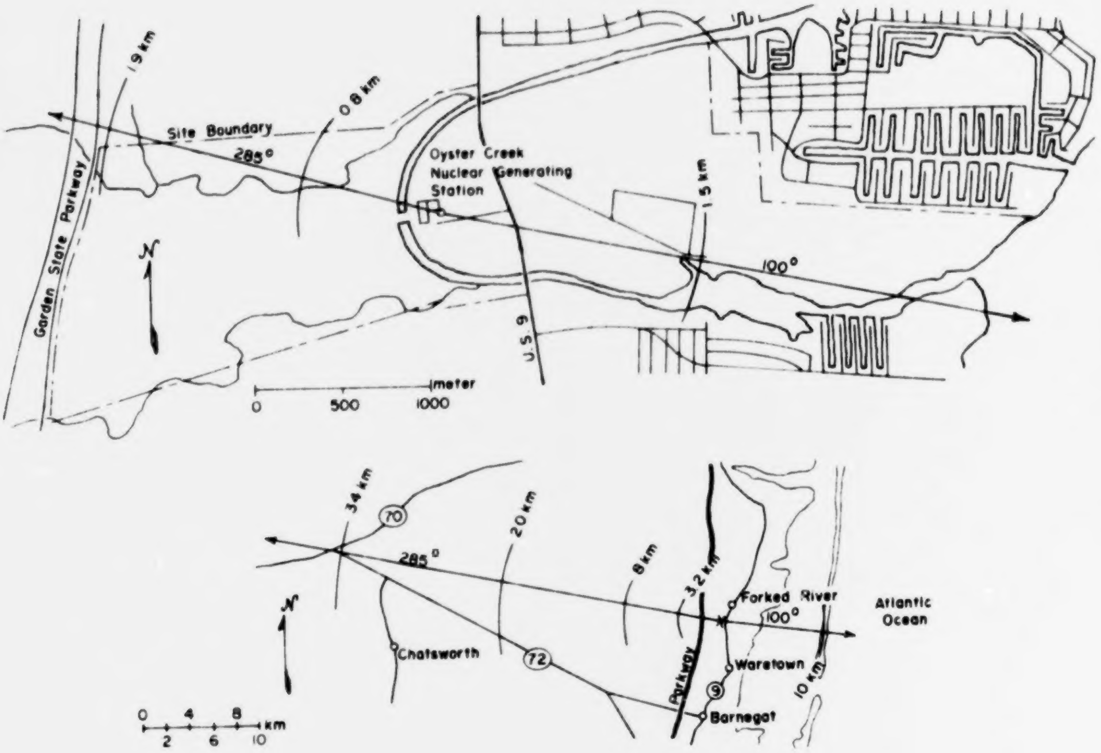
1.9 km
0.8 km
Site Boundary
285°
Oyster Creek
Nuclear Generating
Station
1.5 km
100°
Garden State Parkway
N
U.S. 9
meter
0
500
1000
34 km
70
20 km
8 km
3.2 km
285°
Forked River
100°
Atlantic
Ocean
Chatsworth
72
Parkway
9
Waretown
Barnegat
10 km
N
0
4
8
km
2
6
10

Figure 6.11 Locations of ground and aerial plume measurements, April 3 and 4, 1973.

Table 6.3 Radiation Exposure Rates from Plume at Ground-Level on April 3, 1973, uR/hr

		Measured value			
Location	Time	Average	Maximum	Computed value*	
1.5 km E	0945-1000	31	162	94	(C)
	1000-1152	32	160	72	(D)
10 km E	1157-1208	2	6	20	(D)

*Pasquill-Gifford stability class in parentheses; computed value at 1.5 km E for 1000-1152 hours has been divided by 1.4 to correct for long (2-hr) measurement period.

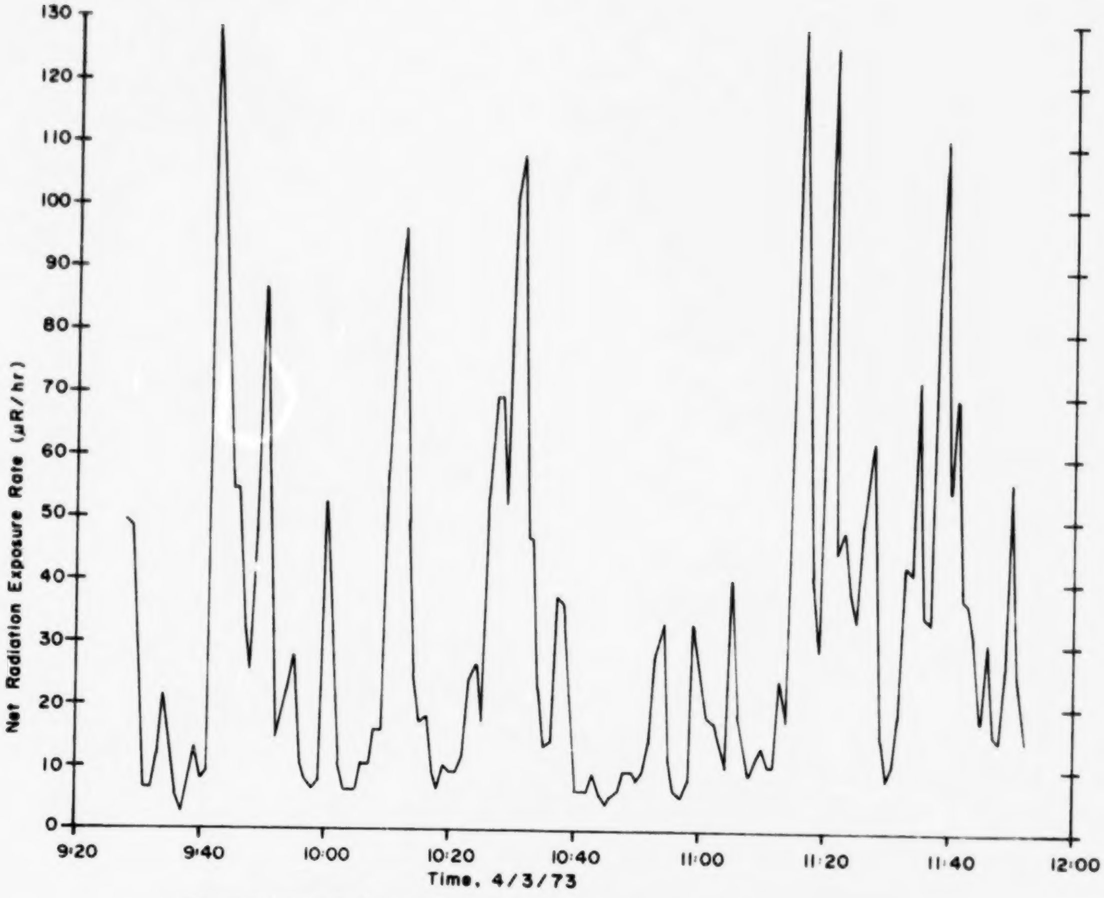

Figure 6.12 Radiation exposure rates 1.5 km east of stack (1-min averages).

At the 1.5-km location, the computed radiation exposure rates using Gamertsfelder's treatment of a finite cloud were two to three times higher than the measured averages.*(16)* The lower measured exposure rates are difficult to explain. The 10-times higher computed value at the 10-km distance may be due to a shift in the wind after the initial measurements or even a different stability condition at the shoreline.

6.3 Helicopter-Borne Measurement of Radiation Exposure

6.3.1 *General.* Radiation measurements in the plume of gaseous effluents from a BWR with airplanes using NaI(Tl) gamma-ray spectrometers,*(18,19)* have shown that this technique is rapid and applicable to terrain unsuitable for ground-based studies. Plumes have been observed 30–50 km*(19,20)* from the stack — far beyond distances where ground-level measurements are feasible. The plume is much more accessible than on the ground; however, the radiation exposures measured in air for a fraction of a minute must be compared with values from models designed for long periods at ground level.

In this test a helicopter, provided by the U.S. Coast Guard,* was used instead of an airplane, and a muscle-equivalent ionization chamber instead of NaI(Tl) detectors. The helicopter permits measurements nearer the ground, slower traverses of the plume and more prompt successive traverses. The muscle-equivalent chamber with a Keithley electrometer and recorder directly yields radiation exposure rates (see Section

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*We thank Cmdr. Alan G. Dahms, U.S. Coast Guard, for making available a helicopter and crew.

6.2.1). The test was intended (a) to observe the fluctuations of exposure rates on the ground, (b) to compare measurements in the air and on the ground, and (c) to obtain exposure-rate gradients of the plume at several elevations and distances.

6.3.2 *Procedure.* Radiation exposure rates were measured at the eight locations listed in Table 6.4 and shown in the area and detailed maps of Figure 6.11. The muscle-equivalent chamber was placed in a Sikorsky HH3F helicopter almost directly beneath the rotor and engine. One staff member operated the instrument and recorded the time and all information relayed from the cockpit concerning location and altitude. Another staff member, in the cockpit, directed the flight pattern according to the study plan and radiation readings observed with a survey meter. The helicopter flew at an average speed of 33 m/s (65 knots). It approached within 0.8-km of the stack at an elevation of 270 m, circled to locate the plume, then traversed the plume at successively lower elevations at 30-m intervals. The helicopter then flew away from the stack, within the plume, to the next selected traverse distance. These distances, and angles at which exposure rates were at maximum, were established from a computer in the helicopter, supplemented with visual location of landmarks. When, after passing through the plume, the exposure readings had returned to background values, the helicopter turned and flew 30-m higher to make the next traverse in the opposite direction. In a few instances, a traverse was repeated.

The muscle-equivalent chamber readings were corrected for the 10-s response time of the system. Most of the delay was due to the ion collection time in the chamber. Numerical integration with experimentally observed rise-time curves of the system showed, for example, that a radiation exposure rate profile in the shape of a normal distribution curve with a standard deviation of 3 s would result in an observed profile with the same area, but lagging by 2 s. The observed peak value would be 0.82 of the actual, and the observed standard deviation would be 3.6 s. This example was typical of profiles found 0.8–1.9 km from the stack. At greater distances, the time in the plume was longer, and the correction was correspondingly less.

The indicated direction of the maximum reading during each traverse was corrected for the above-mentioned time lag in instrument response. Reversed flight directions on alternate traverses minimized any consistent directional error. These corrected values showed plume directions consistently at 100° and 285°.

Meteorological data for computing the diffusion of radionuclides from the stack, and the resulting radiation exposure rates, were obtained from the station's meteorological tower at several elevations to 122 m and from the observations of a participating meteorologist. The meteorological data are summarized in Table 6.1 and discussed in Section 6.2.3.

Radiation exposure rates from the plume were computed by Gamertsfelder's treatment of a finite cloud*(16)*(see Section 6.2.6). For the very brief periods of measurement by helicopter, standard deviations for puffs computed according to Table 4.23 in Reference 16 were also used. The wind speeds applied in the calculations were from meteorological-tower data for

Table 6.4 Aerial Measurement Locations

Date and time	Direction from stack	Distance from stack, km	Altitude above sea level, m
April 3, 1973:	East (100°)		
1526-1532		1.5	120-210
1543-1547		10	120-210
April 4, 1973:	West (285°)		
0813-0831		0.8	120-300
0836-0854		1.9	120-270
0858-0916		3.2	120-270
0933-0948		8	120-270
0957-1017		20	120-270
1023-1031		34	210-360

the measurement periods, as given in Table 6.1. The vertical distance from the plume centerline to the measurement location was taken to be zero at the highest radiation-exposure rates in the helicopter, and 140 m from plume to ground. The plume rise was computed to be 28 m above the 112-m stack.

6.3.3 *Description of plume.* Profiles in the vertical plane of the radiation exposure rates measured on April 4 at distances between 0.8 and 34 km from the stack are shown in Figure 6.13 and summarized in Table 6.5 for peak value and standard deviation at the elevation of maximum exposure. Many of the plumes near the stack, for which traverses required less than 10 s, resemble normal distribution curves; others show irregularities indicating that the plume moved. Plume motion is also seen in the irregularities of maximum values during traverses at successive elevations. The altitudes of maximum exposures at 1.9–20 km distances are consistent with the combined stack height plus plume rise of 140 m, but at 0.8 km the plume centerline appeared to be approximately at the 112-m stack height. The maximum exposure rates and plume dimensions were the same at distances of 0.8 km and 1.9 km, then decreased with distance by approximately

$$\log \mu R/hr = 2.3 - \log km$$

to 34 km.

The measured maximum exposure rates were considerably lower at all distances than the values computed for a finite cloud (see Table 6.5) with standard deviation values for either plume or puff at the appropriate class D stability. The two sets of computed values and the measured values appear to converge at a distance greater than 34 km, presumably because the plume becomes large and the transit times long. The standard deviations of the computed radiation exposure — inferred in Figure 7.12 of Reference 16 to be somewhat larger than the standard deviations of the concentration at the four nearby locations and equal at the two distant ones — are approximately the same as the value for the measured profiles (see Table 6.5 and Figure 6.13) between 1.9 and 20 km. The computed value is less at 0.8 km and more at 34 km.

6.3.4 *Comparison of airborne and ground-level measurements.* Radiation exposure rates measured from the helicopter in the plume at the two locations to the east of the stack (see Table 6.6) and those on the ground (see Table 6.3) are not directly comparable because the helicopter was available in the afternoon but not during the morning. However, conditions were similar for wind direction, wind speed and atmospheric stability during the two measurement periods.

The indicated maximum exposure rate was observed near an altitude of 150 m; centerline values at altitudes of 120, 270, and 300 m were approximately half as great. Qualitatively, the maximum exposure rates measured from the helicopter were expected to be higher than the ground-level maxima, but this was not the case. The values measured in air may have been lower due to:

(a) a larger plume in the afternoon, under the somewhat unstable atmospheric conditions;
(b) radiation shielding by the helicopter, particularly by the engine and fuel tanks;
(c) maximum in the vertical plume profile located between successive traverses; and
(d) disturbance of plume by the helicopter rotor.

The computed values in Table 6.6 show the considerable influence of the assumed stability condition: the plume values for class C are approximately 1.5 times the measured values, while those for D are three to eight times as high. Calculation of exposure rates for "puff" dimensions (Reference 15, p. 175, Table 4.23) is believed to be more applicable than "plume" exposures because the passage of the

Table 6.5 Radiation Exposure Rates at Centerline of Plume West of Plant

Distance from stack, km	Computed exposure rate, μR/hr		Measured values		
			Max. exposure rate, μR/hr	Height above ground at max. exposure, m	Horizontal standard dev. of profile, m
	Plume	Puff			
0.8	650(D)	1500(D)	110	≤100	90
1.9	270(D)	590(D)	110	110-170	90
3.2	140(D)	300(D)	47	110-200	150
8	39(D)	100(D)	25	90-150	300
20	13(D)	35(D)	9.5	90	430
34	5(D)	11(D)	4.5	---	1000

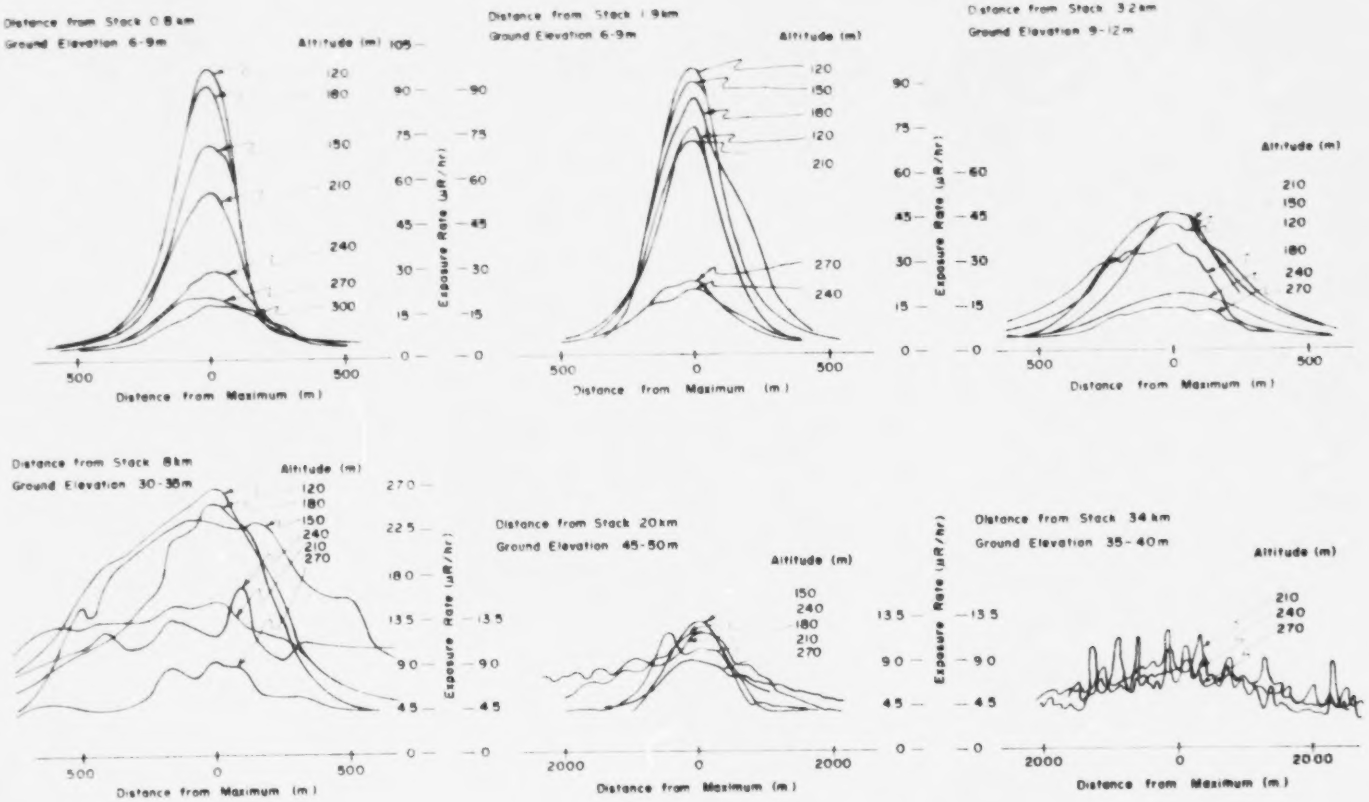

Figure 6.13 Radiation exposure rates measured in helicopter, April 4, 1973.

Table 6.6 Radiation Exposure Rates at Centerline of Plume East of Plant

Distance from stack, km	Computed exposure rate, μR/hr		Measured values		
	Plume	Puff	Max. exposure rate, μR/hr	Height above ground at max. exposure, m	Horizontal standard dev. of profile, m
1.5	180(C)	210(B)	130	150	180
	430(D)	880(D)			
10	10(C)	12(B)	6	120-180	280
	50(D)	120(D)			

helicopter through the cloud took seconds rather than the 10- to 15-min period for which the plume dimensions are usually computed (Reference 11, p. 6) but the puff values differed even more from the measured ones.

6.3.5 *Conclusions.* This initial test indicates some of the advantages in using a helicopter to measure radiation exposure rates due to BWR stack release:

(a) Capability of flying as low as 100 m above ground over unpopulated areas yields plume rise, indicated by a maximum in radiation exposure as a function of height.

(b) Maneuverability for obtaining many measurements in a brief period can define the plume in terms of exposure rate gradients. In 140 minutes, the described plume was traversed at six altitudes at each of the six locations between 0.8 and 34 km distant from the stack.

(c) Measurements of radiation exposure gradients — plume profiles — in all three dimensions could provide a more detailed description of atmospheric stability than the factors now used for this purpose. Applied to research, these measurements can provide fundamental definitions of stability conditions; applied to evaluating radiological models, such measurements can better define conditions if the topography is complex and can yield more precise calculations if it is simple.

(d) The helicopter shares with the airplane the capability of following the radioactive plume to relatively great distances, where the plume could not be so definitely measured, or even identified, from the ground.

In future tests, measurements at ground level and from the helicopter should be performed simultaneously to permit direct comparisons. Measurements obtained at twice the vertical centerline, i.e., the reflections in air of ground-based values, should be of particular interest for comparing airborne and ground-based exposure rates.

Artifacts that may affect the airborne measurements should be identified. It will be desirable to shorten the ionization chamber response time by increasing the applied voltage, and to calculate and measure the radiation attenuation at the detector due to the helicopter.

The observations indicate that the radioactive plume could be detected beyond 34 km at the indicated release rate and meteorological conditions. With more numerous measurements, the rise of the plume and its vertical and horizontal spreading should be readily definable as a function of local topography and atmospheric stability. Availability of a more appropriate model for computing exposure rates would be desirable. To match the measurements, the model should be revised to define the plume for periods of 0.2 to 2 min in terms of radiation exposure rate.

6.4 Direct Gamma-ray Radiation from the Station.

Gamma-ray radiation being emitted directly from buildings at the Oyster Creek station was measured during several field trips. Measurements were made with NaI(Tl) portable survey instruments, described in 6.2.1, supplemented by measurements with the muscle-equivalent ionization chamber with a Keithley electrometer. During one trip, measurements were made to compare results of the muscle-equivalent chamber with Shonka electrometer and a pressurized ionization chamber operated by staff of the AEC Health and Safety Laboratory (HASL).

Gamma exposure rate measurements were made with the survey meter on October 6, 1971, along a line beginning outside the northeast corner of the plant security fence and progressing northeasterly toward the Route 9 highway bridge over the intake canal. Exposure rates shown in Table 6.7 were found to

Table 6.7 External Radiation Exposure Rates On-Site

Distance,* km	Total exposure rate on October 6, 1971, μR/hr**
0.18 NNE	18.4
0.23 NNE	10.0
0.29 NNE	7.7
0.35 NNE	7.6
0.43 NNE	7.5
0.70 NNE	6.0
0.45 E	6.1⁺

* Distance from center of radwaste building.

** Natural background exposure rate in this area is approximately 4.3 μR/hr.

⁺ Measured on December 12, 1972.

decrease with distance from the radwaste building. An attempt was made to evaluate exposure rates off-site by extrapolating from the higher values measured on-site. The distance of each measurement location from the center of the radwaste building appeared to be the critical parameter in correlating the exposure and distance measurements. It is possible that direct radiation from the stack may also contribute to the measured exposure. However, due to the close proximity of the stack to the radwaste building the relationship between distance and exposure rate would not change. The values of exposure rate, above the natural background radioactivity of 4.3 μR/hr, measured on-site were found to fit the equation:

$$R = 0.9\,D^{-2}\exp(-4D)$$

where R is the net radiation exposure rate (background subtracted) in μR/hr and D is the distance in kilometers from the center of the radwaste building. The constant of 0.9 was obtained from the net exposure rates found on-site by a least squares evaluation of the data. The exponential constant of 4 accounts for the attenuation of the gamma-ray radiation in air. From this relationship the exposure rate at the nearest residence, 1.1 km north of the plant, is estimated to be 0.08 mR/yr. A similar relationship between exposure rate from direct gamma-ray radiation and distance from the waste storage tanks was found at the Haddam Neck station.*(5)* In that study the constant was found to be 1.4 instead of 0.9. This difference is probably due to different gamma-ray energies in the wastes and different shielding at the two stations. The contribution of ^{16}N to the exposure rates is not considered to be significant at the Oyster Creek measurement locations. Measurements by HASL indicate that elevated exposure rates due to ^{16}N are to be found west of the turbine centerline.*(21)* ^{16}N gamma-rays were shielded by the reactor building at the locations studied in the preceding measurements.

On October 6 and October 19, 1971, exposure rate measurements were made along the west and north boundaries of the site, using the NaI(Tl) survey meter. Exposure rates were found to range from 4.4 to 6.0 μR/hr at the time of the survey. Variations appear to be due to natural variability in soil radioactivity — the rates measured beside the Garden State Parkway, which forms the west site boundary, were highest — and are not attributed to station operations.

Several comparisons between the muscle-equivalent ionization chamber and the HASL pressurized ionization chamber were made on January 18, 1972, as shown in Table 6.8. The third and fourth measurements show good agreement for natural radiation backgrounds at slightly different levels. The first two are on-site measurements that, according to HASL staff,*(22)* include direct radiation with a relatively low-energy component from stored waste in the first case, and the very strong gamma rays (6.1 and 7.1 MeV) of 7.1-s ^{16}N in the turbines in the second case. The greatest difference is 15 percent.

Exposure rates were measured with the muscle-equivalent ionization chamber along the east plant site boundary on Route 9 when the plume was blowing to the west on December 12, 1972. The results of these measurements are shown on Figure 6.14, where it can be seen that exposure rates above the natural background level of 4.3 μR/hr were measured opposite the plant. The highest net exposure rate (about 1.8 μR/hr above background) was found at the location nearest the stack and the radwaste building. Estimation of the dose due to sources in or near the radwaste building at the nearest location on Route 9 given by the equation above leads to an estimated dose of 1.7 μR/hr above background, comparable to the net measured exposure rate of about 1.8 μR/hr. The average net exposure rate above background attributable to direct radiation from the plant along Route 9 is estimated from this survey to be 0.8 μR/hr between the bridges over the intake and discharge canals. An individual driving at 64 km/hr (40 mph) over this distance would be exposed to 0.012 μR per passage. Assuming 5000 cars per day with an average 1.5 persons per car leads to an annual population dose of 0.034 man-rem.

Measurements were made on-site to the west of the plant, in areas expected to be primarily exposed to high-energy gamma rays from ^{16}N in the turbine, on December 13, 1972. The total exposure rate at a location near the meteorological tower, about 340 m

Table 6.8 Comparison Between Ionization Chamber Measurements, µR/hr

Location	MEIC*	PIC**
1. N.E. corner of security area, on-site	81.1	87.2
2. S.W. of plant, on site (HASL-B)	21.5	25.0
3. 2.7 km SSE of plant	5.3	5.5
4. 7.1 km N of plant	6.1	6.2

[*] Muscle-equivalent ionization chamber.

[**] Pressurized ionization chamber; measurements performed by HASL.

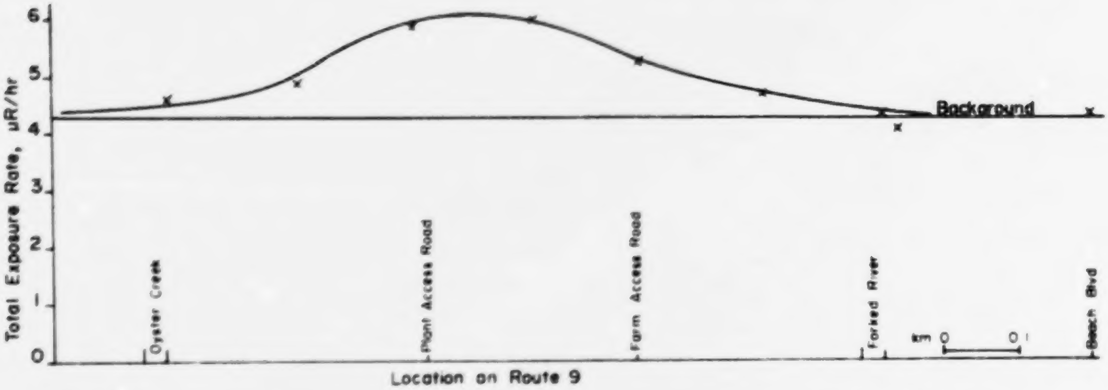

Figure 6.14 Gross exposure rate profile east of Oyster Creek Nuclear Generating Station, December 12, 1972.

west of the turbine building, was measured to be 8.7 µR/hr. The total exposure rate 180 m from the turbine building, near the switchyard, was found to be 21.1 µR/hr. These values agree well with those determined by HASL staff between August 1971 and January 1972 using pressurized ionization chambers and a NaI(Tl) gamma-ray spectrometer system.*(21)* A gamma-ray spectrum obtained with a NaI(Tl) detector during this measurement is shown in Figure 6.15.

6.5 Long-term Radiation Exposure Measurements

6.5.1 *Measurements.* Long-term exposure measurements were obtained in the vicinity of the station with thermoluminescent dosimeters (TLD). Measurements were made during the periods of September 29 to November 30, 1971, March 14 to June 15, 1972, and April 17 to July 2, 1973. Two to six dosimeters were placed at each of the locations shown on Figures 6.16 and 6.18. Monitoring sites were selected to surround the station as much as possible. Some of these sites (101, 108 and 109) coincided with TLD stations established by HASL. Background values at each site were obtained when the station was not operating and operational values while the station was operating.

The TLD system, manufactured by EG&G, utilizes the model TL-3B reader' and model TL-15 bulb-type dosimeters. The dosimeter is a hot-pressed CaF_2:Mn cylinder bonded to a heater element contained in an evacuated glass tube. The bulb is enclosed in an aluminum-lead-tin shield to eliminate detector over-response to gamma rays below approximately 100 keV. It detects gamma rays with energies above 60 keV. Calibration factors and internal background for each dosimeter were determined in the laboratory.*(23)*

The dosimeters used during the first two sets of measurements had not been fully evaluated in the laboratory. As discussed later, these measurements indicated that more laboratory testing of the dosimeters was necessary before environmental

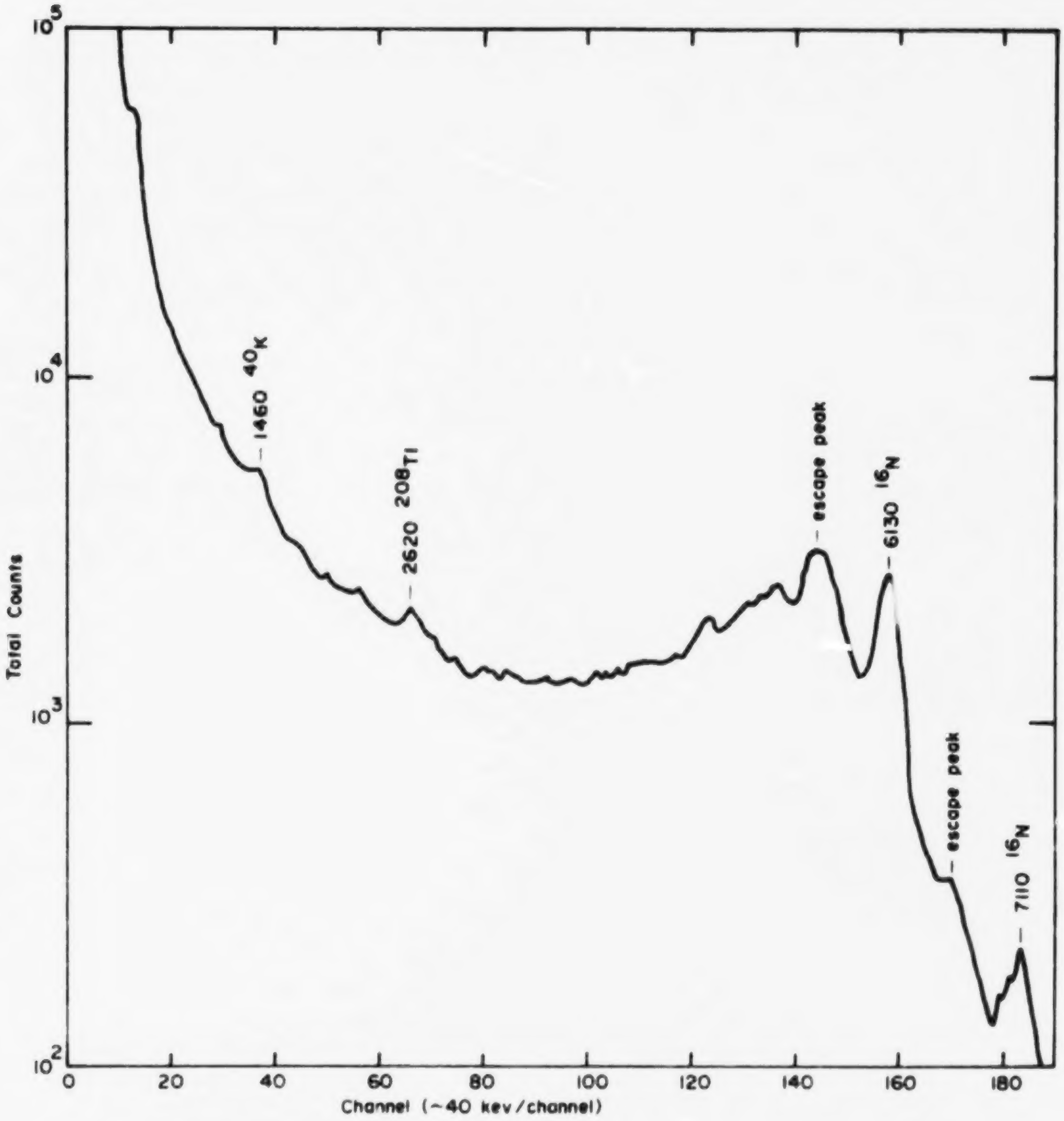

Figure 6.15 Gamma-ray spectrum of ^{16}N direct radiation from turbine building, measured 0.2 km west of building.
Detector: 10-x10-cm NaI(Tl)
Count: Dec. 13, 1972, 40 min (background not subtracted).

measurements could be performed with confidence and that dosimeters with lower internal self-dosing characteristics were desired. Improvements in dosimeter design led to the use of the dosimeters discussed below for the third measurement period.

Calibration factors for converting arbitrary dosimeter units to exposure in mR were determined by exposing each dosimeter eight times to 5 mR to 10 mR gamma-ray radiation from a 2 mCi radium-226 standard and reading the dosimeters 24 hours later. The mean calibration factors of the 94 dosimeters varied from 0.20 to 0.27 mR/reader unit. The average standard deviation (1 σ) was 1.8 percent. This represents the reproducibility of reading these dosimeters at typical environmental radiation levels under laboratory conditions.

Studies of dosimeter fading indicated that most occurs within 5 hours of exposure. Between 5 hours and 24 hours the fade is about one percent with no measurable fade after 24 hours. Therefore, no fading correction is necessary for environmental monitoring where the dose is accumulated over 2 to 4 weeks.

The internal background (self-dosing) of the dosimeters, from radioactivity in their component materials, was determined by placing annealed dosimeters for 160 hours in a shield with 15-cm-thick steel walls. The natural background exposure rate in the shield was measured with a muscle-equivalent ionization chamber to be 2.0 μR/hr. The internal background of each dosimeter was determined in 5 to 10 measurements by subtracting the natural background from the dosimeter reading. The average internal background for the 94 dosimeters of the type used in the last set of measurements was 1.98 ± 0.09 μR/hr (average of the standard deviations of the individual dosimeters).

A minimum detectable level can be defined as three times the standard deviation associated with the background measurement. As an example, assume that the dosimeter was placed in the field for a 1-month monitoring period. At the end of the 720 hours, the dosimeter would have accumulated 1.43 ± 0.06 mR from internal background alone. Therefore, the minimum detectable exposure for a 1-month monitoring period is calculated to be three times 0.06 mR or 0.18 mR for a single dosimeter. For multiple dosimeters, the minimum detectable exposure would be less. Thus, a typical natural background radiation exposure level of 6 mR/month can be readily measured with TLD's. However, there is greater uncertainty in determining an increase above the natural background because the latter fluctuates by several μR/hr. The minimum detectable increase above natural background radiation exposure contributed by a nuclear power station which can be measured by TLD is typically 1 μR/hr if some of these fluctuations can be quantified.*(24)*

For field measurements, the TLD reader was located in an EPA laboratory at Edison, N. J., during the first two periods and in Forked River, N. J., during the third period, so that the dosimeters could be read within 6 hours after collection and returned immediately to their monitoring locations. This procedure minimized any unknown exposures occurring during transportation over long distances to and from the laboratory. The maximum error in the results due to the dosimeters not being on location during transportation and readout is estimated to be equivalent to 0.1 μR/hr. Values obtained from the two to six dosimeters at a given location were averaged. In five instances results were lost because dosimeters were missing from the measurement location.

During dosimeter placement and retrieval, the external radiation exposure rate at the location was measured with the 5- x 5-cm NaI(Tl) survey meters. The mean 2σ values for these measurements was ± 0.3 μR/hr. In a previous study,*(3)* readings with adequately calibrated survey meters corresponded closely to the TLD results except for time-dependent differences, since the survey meter gives an instantaneous value whereas the TLD integrates the exposure over several weeks.

To facilitate analysis, TLD measurements have been divided into two groups — eight periods during September 29, 1971 to June 15, 1972 and two periods during April 17 to July 2, 1973. For the first group of measurements, the plant was operating during a part of the third period and during the fourth and fifth periods. The TLD reader and dosimeters were provided by the EPA Eastern Environmental Radiation Facility. Dosimeters were placed in 20-cm x 45-cm clear plastic bags and attached 2 m above ground to trees or poles at the selected sites. After three measurement periods, the dosimeters were returned to the laboratory for testing, and later replaced at the measurement locations for an additional five periods. On November 18 and 19, 1971, measurements were made simultaneously with the muscle-equivalent ionization chamber at four of the TLD locations.

A new batch of dosimeters that had relatively low self-dosing characteristics was placed around the station from April 17 to June 4, 1973, while the plant was not operating and from June 4 to July 2, 1973, while the plant was operating in a normal manner. These dosimeters were placed in 7.5-cm x 10-cm clear plastic bags which made them less conspicuous and reduced theft.

6.5.2 *Results.* Measurements during the first group of eight periods were made at the locations shown on Figure 6.16. Measurements at location 102 were discontinued due to frequent theft. Measurements at location 112 were discontinued when residential development began.

Results of the first group of measurements are shown in Table 6.9. The environmental exposure rate was found to vary between 5.0 and 9.6 μR/hr. The natural background is relatively low in the area, undoubtedly because of the sandy soil, and increases gradually with increasing distance from the seashore. The TLD values appear to be reasonably consistent with the survey meter readings and the few ionization chamber readings.

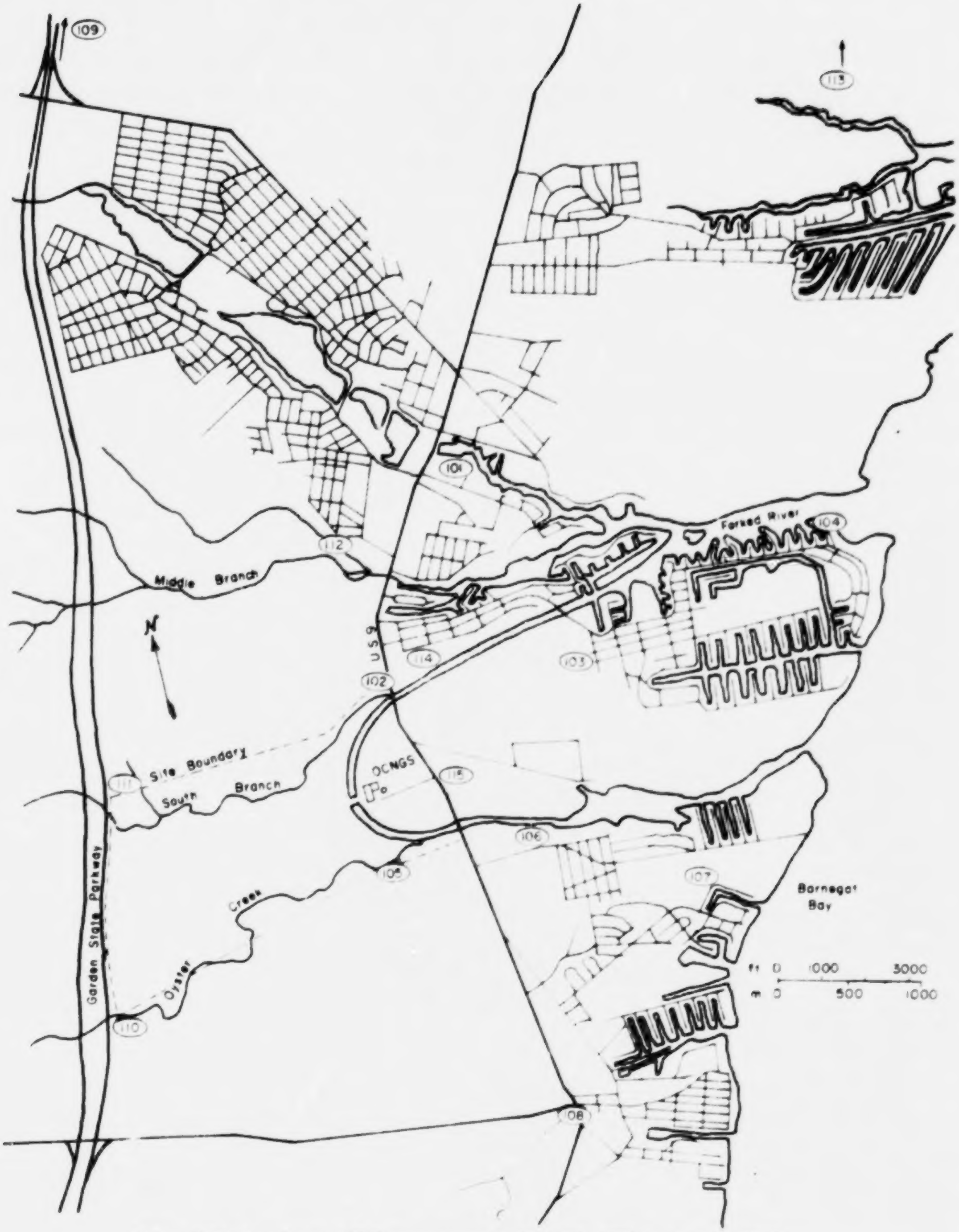
109
113
101
Forked River
104
112
Middle Branch
N
US 9
114
103
102
Site Boundary
OCNGS
115
111
South Branch
106
105
107
Barnegat Bay
Oyster Creek
Garden State Parkway
110
108
ft 0 1000 3000
m 0 500 1000

Figure 6.16 Locations of TLD measurements, Sept. 29, 1971 to June 15, 1972.

Table 6.9 Long-Term Exposure Rate Measurements, μR/hr (September 29, 1971 to June 15, 1972)

Location	9/29-10/18/71[1] TLD	9/29-10/18/71[1] Survey meter	10/18,19-11/11/71[1] TLD	10/18,19-11/11/71[1] Survey meter	11/12-30/71[2] TLD	11/12-30/71[2] Survey meter	11/18,19/71[2] Shonka	3/14-4/4/72[3] TLD	3/14-4/4/72[3] Survey meter
101	5.6 ± 0.1	5.0	5.3 ± 0.2	5.0	5.5 ± 0.3	5.1		6.6	5.1
102	7.1 ± 0.1	7.1	7.1 ± 0.2	7.1	lost	7.0			
103	5.1 ± 0.2	5.5	6.1	5.4	6.1 ± 0.5	6.2*		5.4 ± 0.2	5.3
104	6.5 ± 1.1	5.2	6.1 ± 0.1	4.9	5.8 ± 0.2	5.2		5.4 ± 0.1	4.9
105	6.7 ± 0.2	6.6	7.3 ± 0.3	6.6	7.7 ± 0.2	7.0	7.5	9.6 ± 0.2	8.6
106	5.2 ± 0.4	5.7	5.3 ± 0.5	5.5	6.5 ± 0.2	5.6	5.3	7.4 ± 0.3	8.1*
107	5.6 ± 0.4	5.9	5.4 ± 0.3	5.3	6.3 ± 0.1	5.7		5.9 ± 0.0	6.8*
108	5.3 ± 0.8	5.8	6.0 ± 0.1	5.5	6.7 ± 0.0	5.8	5.3	6.1 ± 0.0	5.5
109			7.2 ± 0.3	6.9	7.8 ± 0.2	7.1	6.1	6.4 ± 0.1	6.7
110	6.3	6.0	7.5 ± 0.1	5.7	6.8 ± 0.1	5.9		6.1 ± 0.0	5.8
111	6.5 ± 0.2	5.8	7.4 ± 0.4	5.8	7.0 ± 0.1	6.0		6.3 ± 0.1	5.8
112	5.1 ± 0.5	5.4	5.9 ± 0.0	5.2	6.4 ± 0.0	5.3			
113								5.4 ± 0.2	5.3
114								6.2 ± 0.6	6.5
115								8.0 ± 0.4	9.0

	4/5-20/72[3] TLD	4/5-20/72[3] Survey meter	4/21-5/8/72[1] TLD	4/21-5/8/72[1] Survey meter	5/9-31/72[1] TLD	5/9-31/72[1] Survey meter	6/1-15/72[1] TLD	6/1-15/72[1] Survey meter
101	6.5 ± 0.0	6.0	6.7 ± 0.3	5.0	5.8 ± 0.2	5.3	5.0 ± 0.1	4.6
103	6.2 ± 0.2	6.0	6.3 ± 0.1	5.1	5.4 ± 0.2	5.6		
104	6.2 ± 0.0	5.0	6.2 ± 0.2	4.6	5.7 ± 0.2	4.6	5.4 ± 0.1	4.8
105	9.6 ± 0.1	10.8	lost	6.8	6.3 ± 0.2	7.0	5.8 ± 0.1	6.9
106	6.8 ± 0.3	8.1*	5.7 ± 0.1	5.5	5.2 ± 0.3	5.6	5.1 ± 0.0	5.7
107	5.7 ± 0.1	5.6	5.0 ± 0.1	5.0	5.1 ± 0.0	5.2		5.0
108	6.3 ± 0.0	5.7	5.9 ± 0.0	5.7	5.9 ± 0.1	5.7	5.1 ± 0.2	5.7
109	6.9 ± 0.2	6.7	6.6 ± 0.1	7.4	6.6 ± 0.5	6.6	6.3 ± 0.5	7.1
110	6.5 ± 0.2	6.3	6.8 ± 0.2	5.7	6.3 ± 0.1	5.8	lost	5.8
111	7.0 ± 0.1	5.9	6.4 ± 0.1	5.7	6.0 ± 0.1	5.9	lost	5.9
113	6.0 ± 0.0	5.9	5.6 ± 0.3	5.3	lost	5.4	5.6 ± 0.4	5.5
114	7.6 ± 0.1	7.3	7.3 ± 0.5	5.9	5.7 ± 0.4	6.4	5.6 ± 0.5	6.4
115	8.6 ± 0.3	21.9*	7.9 ± 0.5	7.0	6.2 ± 0.4	7.2	6.2 ± 0.7	6.8

* In plume at time of measurement

[1] Plant not operating.

[2] Plant operation variable.

[3] Plant operating

Note: ± values are 1σ.

Exposure rates measured while the station was operating and when it was not operating were averaged. The difference between the two averages represents exposure due to station operation in the absence of significant changes in the natural radiation background.

Radiation exposure rates during station operation were estimated (Table 6.10) using the method of Burke.*(25)* This assumes that the exposure rate due to the plume of radioactive gases from the stack varies inversely with distance from the stack, weighted by the wind direction frequency from data reported by the station operator for the period most nearly coinciding with the period of interest (in this case, March and April 1972).*(26)* The values obtained from the model were then normalized to correspond to the measured values. Although the measured net values are not statistically significant at the 2σ level, except for two

Table 6.10 Comparison of Operating *vs.* Shutdown Period Exposure Rates, μR/hr (September 29, 1971 to June 15, 1972)

Location	Distance from Stack (km)	Plant Operating[1]	Plant Not Operating[2]	Net Due To Plant Operation	Estimated Exposure Rate
101	2.5 NNE	6.1 ± 0.1	5.5 ± 0.6	+0.6 ± 0.6	0.5
103	1.7 ENE	5.8 ± 0.6	5.8 ± 0.5	0.0 ± 0.7	0.6
104	3.8 ENE	5.8 ± 0.5	5.8 ± 0.4	0.0 ± 0.6	0.4
105	0.6 S	9.5 ± 0.3	6.6 ± 0.7	+2.9 ± 0.8	2.9
106	1.2 ESE	7.1 ± 0.5	5.3 ± 0.6	+1.8 ± 0.7	0.7
107	2.4 ESE	5.8 ± 0.1	5.2 ± 0.4	+0.6 ± 0.4	0.4
108	2.7 SSE	6.2 ± 0.1	5.8 ± 0.5	+0.4 ± 0.5	1.0
109	7.1 N	6.6 ± 0.3	6.8 ± 0.6	-0.2 ± 0.7	0.1
110	2.6 WSW	6.3 ± 0.3	6.8 ± 0.5	-0.5 ± 0.6	0.4
111	2.0 WNW	6.6 ± 0.4	6.6 ± 0.6	+0.0 ± 0.7	0.6
113	7.9 NE	5.7 ± 0.4	5.6 ± 0.4	+0.1 ± 0.6	0.2
114	1.0 NNE	6.9 ± 0.7	6.1 ± 1.0	+0.8 ± 1.2	1.2
115	0.5 E	8.3 ± 0.6	6.8 ± 1.1	+1.5 ± 1.3	2.0

Note: ± values are 1σ.

[1] Measurements obtained during March 14 to April 20, 1972.

[2] Measurements obtained during September 29 to November 11, 1971 and April 21 and June 31, 1972.

locations, the set of all measured and estimated values are highly correlated, as shown in Figure 6.17. The line of best fit drawn for the 13 points has a correlation coefficient of 0.94.

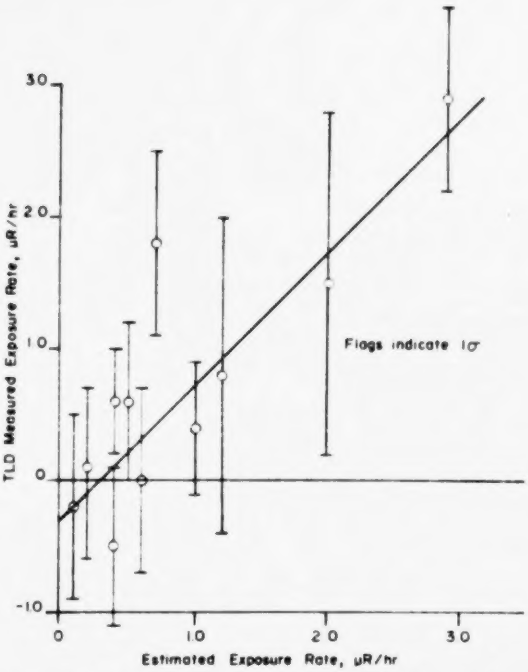

Figure 6.17 Comparison of measured and estimated exposure rates, March 14 to April 20, 1972.

Locations for the second group of measurements are shown on Figure 6.18. Most of these locations are the same as, or very near, the locations used earlier. Results of these measurements are shown in Table 6.11. The environmental exposure rates ranged from 4.3 to 6.5 μR/hr. The TLD values were again relatively consistent with the survey meter readings at the time of collection. Net exposure rates attributed to plant operation were found to be positive in 15 of 16 cases and in 8 cases were found to be statistically significant at the 2σ level.

Exposure rates due to the plume of radioactive gases from the stack were again estimated by the method of Burke and are shown in Table 6.11. Wind direction frequencies were reported by the station.*(27)* The estimated and measured net exposure rates are highly correlated, as shown on Figure 6.19. Lines of best fit for all points (correlation coefficient of 0.64) and for 13 points excluding 3 outlying values (correlation coefficient 0.86) are shown.

Recent studies indicate that instead of using the "invariance with time" technique as above for estimating background exposure rates, a "climate-exposure model" would allow one to more sensitively quantify exposures attributable to station operations with TLD.*(28)* In fact, TLD may be used to determine yearly exposures with standard deviations as low as 0.6 mr. However, this method could not be used at the Oyster Creek Station due to a lack of meteorological data.

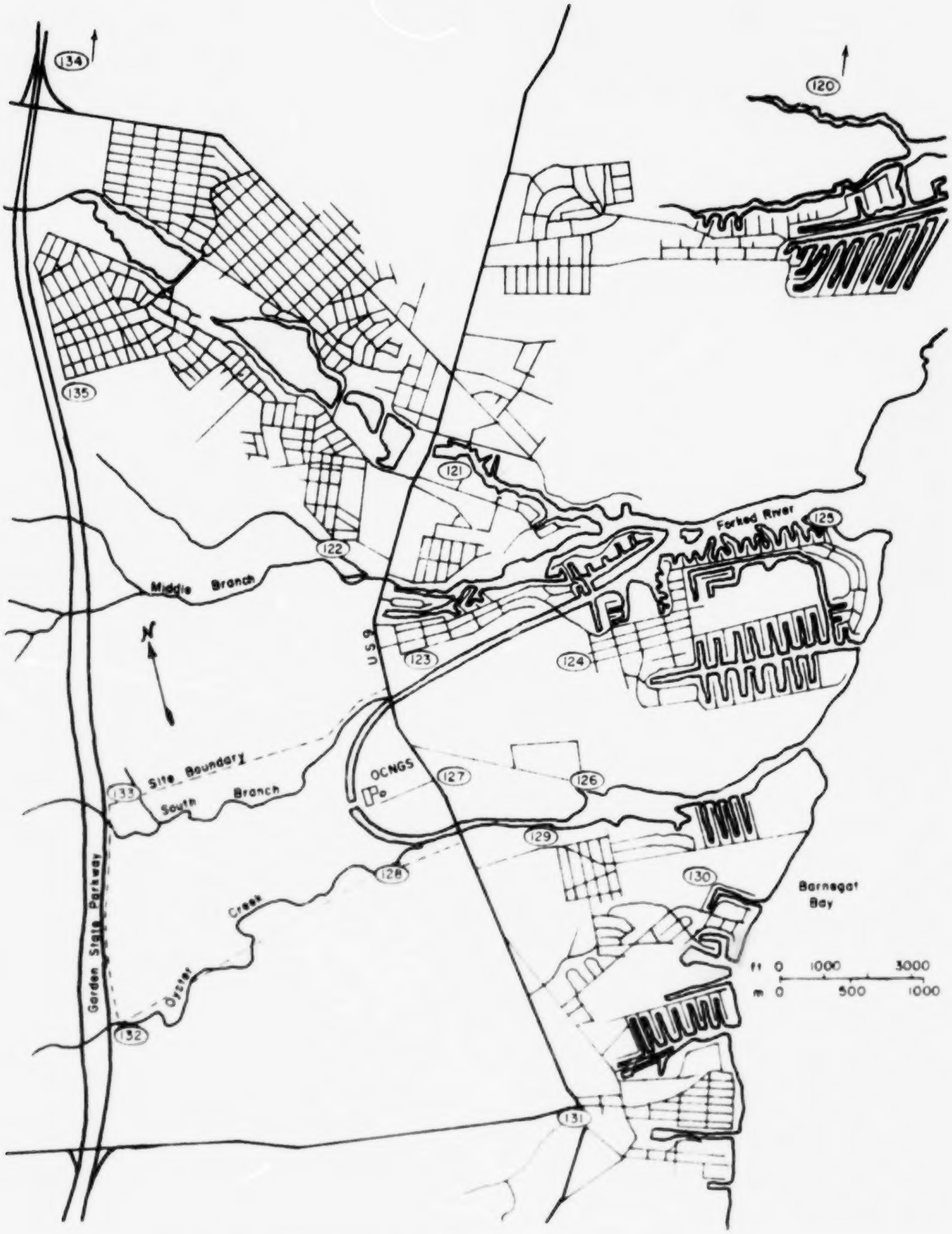
134
120
135
121
122
Forked River
125
Middle Branch
N
U.S. 9
123
124
Site Boundary
133
South Branch
OCNGS
127
126
129
128
130
Barnegat Bay
Oyster Creek
Garden State Parkway
132
131
ft 0 1000 3000
m 0 500 1000

Figure 6.18 Locations of TLD measurements, April 17 to July 2, 1973.

Table 6.11 Long-Term Exposure Rate Measurements, µR/hr (April 17 to July 2, 1973)

		4/17-6/4/73 Plant not operating			6/4-7/2/73 Plant operating			
Location	Distance from stack, km	Survey meter	TLD	Survey meter	TLD	Survey meter	Net due to plant operation	Estimated exposure rate
120	7.9 NE	4.6	4.5 ± 0.3	4.9	4.6 ± 0.5	5.0	0.1 ± 0.6	0.1
121	2.5 NNE	5.0	4.5 ± 0.2	4.9	4.9 ± 0.4	5.1	0.4 ± 0.4	0.3
122	2.2 N	4.2	4.3 ± 0.1	4.6	4.8 ± 0.1		0.5 ± 0.1	0.2
123	1.0 NNE	5.7	4.8 ± 0.[illegible]	5.9	5.5 ± 0.2	6.1	0.7 ± 0.5	0.7
124	1.7 ENE	4.7	4.5 ± 0.0	5.0	4.9 ± 0.3	5.2	0.4 ± 0.3	0.5
125	3.8 ENE	4.1	4.4 ± 0.2	4.5	4.6 ± 0.4	5.5	0.2 ± 0.4	0.2
126	1.5 E	4.6	4.3 ± 0.2	5.1	4.6 ± 0.3	5.2	0.3 ± 0.4	0.6
127	0.5 E	8.6	4.5 ± 0.4	6.8	6.5 ± 0.2	7.1	2.0 ± 0.4	1.7
128	0.6 S	7.5	5.4 ± 0.2	6.6	5.2 ± 0.3	8.4*	-0.2 ± 0.4	0.6
129	1.2 ESE	5.0	4.6 ± 0.0	4.7	4.8 ± 0.1	5.9	0.2 ± 0.1	0.8
130	2.4 ESE	4.5	4.4 ± 0.2	4.6	4.5 ± 0.2	6.9	0.1 ± 0.3	0.4
131	2.7 SSE	4.9	4.6 ± 0.3	5.1	4.8 ± 0.4	5.1	0.2 ± 0.5	0.3
132	2.6 WSW	4.9	4.9 ± 0.1	5.1	5.7 ± 0.4	5.9	0.8 ± 0.4	0.2
133	2.0 WNW	4.6	4.5 ± 0.4	5.0	4.9 ± 0.4	5.5	0.4 ± 0.6	0.2
134	7.1 N	6.1	5.0 ± 0.4	6.6	5.7 ± 0.5	7.4	0.7 ± 0.6	0.1
135	3.8 NNW	7.9	6.4 ± 0.1	8.0	6.7 ± 0.0	8.4	0.3 ± 0.1	0.2

* In plume at time of measurement.

Note: ± values are 2σ.

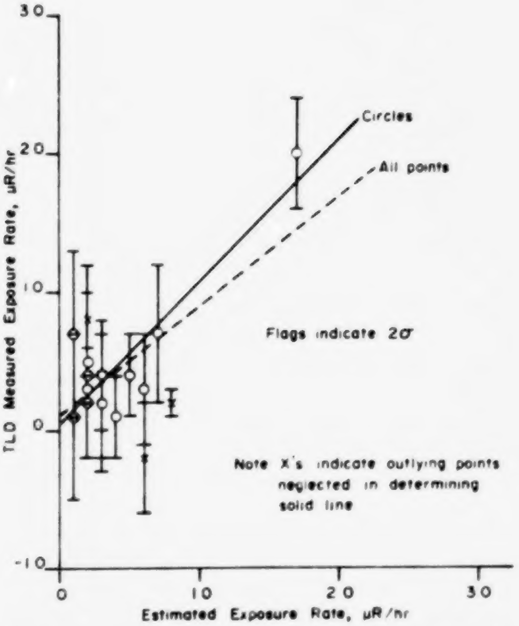

Figure 6.19 Comparison of measured and estimated exposure rates, April 17 to July 2, 1973.

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7. SUMMARY AND CONCLUSIONS

7.1 Radionuclides in Effluents from the Oyster Creek Station

Radionuclides were discharged by numerous pathways in small amounts relative to effluent limits. The most abundant constituents among radioactive effluents were ^{3}H, 61 percent in liquid waste, and the radioactive noble gases, mostly in airborne wastes. Also in the liquid wastes, the activation products ^{51}Cr, ^{54}Mn, ^{59}Fe, ^{60}Co and ^{134}Cs and fission-produced ^{131}I, ^{133}Xe, ^{135}Xe and ^{137}Cs were discharged in relatively large quantities. These observations appear to be generally applicable to large BWR nuclear power stations.

Results of effluent measurements in this study are summarized below, based on the information in Sections 3 and 4. For simplicity, they are given as annual releases. Because these values were obtained by occasional sampling, they should be considered only indications of the magnitude of radionuclide discharges. Exact values must be derived from frequent or continuous measurements at each discharge location.

The estimated amounts of radionuclides in airborne effluents during the second half of 1971 through the first half of 1973 are as follows:

	Radionuclides in airborne effluents, Ci/yr				
Radionuclide	(1) Main condenser steam jet air ejector	(2) Turbine gland seal condenser	(3) Building ventilation air	(4) Reactor drywell	(5) Stack
^{3}H	5.0×10^{-1}	$< 2 \times 10^{-3}$	2.7×10^{1}	8×10^{-4}	2.6×10^{1}
^{13}N	5.0×10^{-1}	5×10^{2}	NA†	NA	NA
^{14}C	3.0	5×10^{-3}	1.2	9.6×10^{-4}	9.1
^{83m}Kr	3.1×10^{4}*	NA	NA	NA	NA
^{85m}Kr	6.9×10^{4}	8.2×10^{1}	NA	NA	NA
^{85}Kr	1.1×10^{2}	1.9×10^{-1}	2.0	2.8×10^{-2}	1.7×10^{2}
^{87}Kr	1.3×10^{5}	2.9×10^{2}	NA	NA	NA
^{88}Kr	1.4×10^{5}	1.4×10^{2}	NA	NA	NA
^{89}Kr	0*	6.2×10^{2}	2.1×10^{2}*	NA	NA
^{131}I	1.7	NA	5×10^{-1}*	NA	1.7×10^{1}
^{131m}Xe	3.7×10^{2}*	NA	NA	NA	NA
^{133m}Xe	5.1×10^{3}	NA	NA	1×10^{-1}	7×10^{3}
^{133}Xe	1.6×10^{5}	2.1×10^{2}	1.0×10^{1}	2.2	1.2×10^{5}
^{135m}Xe	8.8×10^{4}	1.2×10^{3}	NA	NA	NA
^{135}Xe	3.0×10^{5}	4.7×10^{2}	4.0×10^{1}	NA	3.5×10^{5}
^{137}Xe	2.2	1.1×10^{3}*	3.6×10^{2}*	NA	NA
^{138}Xe	6.0×10^{4}	2.0×10^{3}	NA	NA	NA
Long-lived particulate**	NA	NA	NA	NA	5.0×10^{1}

* Calculated value, radionuclide not measured.

**Excluding particulate ^{131}I

† NA – not analyzed.

The values for stack discharge in data column 5 reflect radioactivity from individual waste pathways, columns 1 through 4. Effluent radioactivity from reactor startup, not included since it was not measured, is expected to be a minor contributor. The ^{3}H and ^{14}C values are for all forms of the radionuclides; distinctions between tritiated water and gases and between ^{14}C in CO_2 and other gases are made in Section 3 for most pathways. The amounts of radionuclides in some waste streams were inferred when their contributions were expected to be significant. Short-lived progeny of noble gases, such as ^{88}Rb and ^{138}Cs, and relatively short-lived iodine isotopes, such as ^{132}I, ^{133}I, ^{134}I and ^{135}I, were also expected to be present.

Most stack radioactivity resulted from the air ejectors on the main condensers. Ventilation air contributed most of the ^{3}H effluent. Much of the ^{13}N and short-lived noble gases in stack discharge came from the turbine gland seal condenser.

Airborne effluents are expected to yield a total-body dose of 2.3 mrem/year to an adult residing where the highest annual average concentration occurs (see Section 3.3.10). The closest resident is estimated to receive 0.39 mrem/year, and a member of the closest population group, 2.1 mrem/year. (Actual dose would be lower since residential shielding and occupancy factors were not considered.) Dose to persons fishing in the discharge canal 700 hrs per year is expected to be about 0.1 mrem/year.

The estimated amounts of radionuclides in liquid effluents during the period from August 1971 to November 1973 are as follows:

Radionuclides in liquid effluents, Ci/yr

Radionuclide	Waste sample tank	Laundry drain tank
^{3}H	4×10^{1}	1×10^{-3}
^{14}C	8×10^{-1}	1×10^{-4}
^{32}P	6×10^{-2}	2×10^{-4}
^{51}Cr	5×10^{-1}	3×10^{-3}
^{54}Mn	4×10^{-1}	2×10^{-2}
^{55}Fe	6×10^{-1}	4×10^{-3}
^{59}Fe	7×10^{-2}	4×10^{-3}
^{58}Co	5×10^{-2}	4×10^{-3}
^{60}Co	9×10^{-1}	5×10^{-2}
^{64}Cu	1×10^{-2}	ND
^{65}Zn	5×10^{-1}	ND
^{76}As	5×10^{-2}	ND
^{89}Sr	1×10^{-2}	3×10^{-4}
^{90}Sr	1×10^{-1}	3×10^{-5}
^{95}Zr	2×10^{-2}	1×10^{-3}
^{95}Nb	2×10^{-2}	2×10^{-3}
^{99}Mo	2×10^{-1}	ND
^{103}Ru	1×10^{-2}	2×10^{-4}
^{105}Rh	5×10^{-2}	ND
^{110m}Ag	2×10^{-1}	ND
^{124}Sb	9×10^{-1}	7×10^{-4}
^{131}I	1×10^{-1}	5×10^{-3}
^{133}I	5×10^{-2}	ND
^{133}Xe	9×10^{-1}	ND
^{135}Xe	1	ND
^{134}Cs	2	2×10^{-3}
^{137}Cs	4	4×10^{-3}
^{140}Ba	3×10^{-2}	9×10^{-4}
^{141}Ce	4×10^{-2}	4×10^{-4}
^{144}Ce	3×10^{-2}	9×10^{-4}
^{239}Np	3×10^{-2}	ND

Note: ND – not detected

The bulk of the liquid effluent radioactivity was discharged from the waste sample tanks after treatment and storage. Only a small quantity, generally less than 5 percent, was discharged directly from the laundry drain tanks to the discharge canal. For the 17 radionuclides which could be compared with annual discharges reported by the station operator, agreement was reasonable except for the relatively low measured quantities of ^{239}Np, ^{89}Sr and ^{90}Sr. Further evidence of agreement was derived from the ability to predict radionuclide concentrations in the circulating coolant canal during discharge from pre-discharge measurements of the sample test tank contents and appropriate dilution factors (see Section 4.4).

The results obtained in this study reflect the operations and conditions at the station during the study period, October 1971 to November 1973. According to the station operator, the replacement of original fuel and improved fuel cladding performance since the study period has significantly reduced off-gas release rates. Further reduction of radioactivity in the off-gas from the steam condenser air ejectors will be realized when the plant is fitted with an extended radwaste treatment system. Radioactivity in liquid effluents have also been reported by the station operator to have decreased due to improvements in the radwaste treatment system.

7.2 Radionuclides in the Aquatic Environment at the Oyster Creek Station

Radionuclides from the station were found at low concentrations in various media sampled in the aquatic environment:

(1) The following radionuclides discharged by the station were at concentrations greater than 1

pCi/liter in the coolant canal: ^{51}Cr, ^{54}Mn, ^{60}Co, ^{99}Mo, ^{131}I, ^{134}Cs and ^{137}Cs. In addition, ^{58}Co, ^{59}Fe, ^{95}Zr, ^{95}Nb, ^{141}Ce and ^{144}Ce were detected at concentrations between 0.1 and 1.0 pCi/liter. Concentrations of ^{90}Sr in water from Barnegat Bay and the intake and discharge canals were generally near background levels. Manganese-54 and ^{60}Co were measured at levels up to 2.2 and 4.0 pCi/liter, respectively, in large water samples (76–380 liters) collected from the canals and bay. They were associated mostly with suspended material. Predicted radionuclide concentrations in the coolant canal during discharge agreed usually with measurements (see Section 5.2).

(2) Radionuclides found in station effluents were observed in macro-algae and aquatic grasses collected from all sites in the bay and canals. The predominant radionuclides were ^{54}Mn (0.2–26 pCi/kg) and ^{60}Co (0.2–45 pCi/kg). Some samples contained ^{51}Cr, ^{58}Co, ^{106}Ru, ^{134}Cs and ^{137}Cs in quantities slightly exceeding background concentrations. Highest concentrations were observed usually in *G. verrucosa*, followed by *U. lactuca* and *C. fragile*. Radionuclide concentrations varied significantly with season of the year, presumably resulting from variations in atmospheric fallout, plant growing periods, and time of sample collection relative to discharge. The concentrations of ^{54}Mn and ^{60}Co in algae reflected relative amounts discharged and indicated little uptake from sediment. Algae proved to be sensitive indicators for monitoring radionuclides when water concentrations were below detectable levels (see Section 5.3).

(3) Manganese-54 (to 34 pCi/kg) and ^{60}Co (to 54 pCi/kg) were predominant in fish muscle. Their concentrations generally increased with greater station discharges and decreased with distance from the mouth of Oyster Creek. Small quantities of ^{134}Cs were detected in fish that also contained ^{137}Cs above background levels (see Section 5.4).

(4) Similar concentrations of ^{60}Co were detected in shellfish muscle and fluid, ranging from 120–260 pCi/kg. Almost all ^{60}Co in fluid was associated with protein. Although not detected in clam muscle, the shells of clams from Barnegat Bay contained twice as much ^{90}Sr as those from the background area, 190 *vs.* 105 pCi/kg. Barnacles collected from both canals contained ^{54}Mn, ^{58}Co, ^{60}Co, ^{90}Sr and ^{137}Cs from the station, and, being fixed in position, they provide good indicators of station discharges. Differences in concentration in barnacles from the discharge and intake canals indicated that 10 to 15 percent of the station effluent is recirculated. The radionuclide of highest concentration in clams was naturally-occurring ^{210}Po, 230 to 500 pCi/kg muscle, which is not attributed to reactor operations. An average ^{210}Po/^{210}Pb activity ratio of 9 indicated clam food (algae and plankton) was the probable source of the ^{210}Po (see Section 5.5).

(5) No effluent radionuclides were detected in crab muscle, gills, gut or stomach, although the exoskeletons of some from Barnegat Bay contained more ^{54}Mn and ^{90}Sr than background samples. Because the exoskeleton is not eaten and is periodically molted, little useful information can be obtained from these analyses (see Section 5.6).

(6) In sediment, ^{60}Co was the most widely distributed radionuclide, ranging from 0.26 to 18.6 pCi/g in the discharge canal to less than detectable quantities at the extremities of Barnegat Bay. Some sediment contained ^{54}Mn, ^{134}Cs and ^{137}Cs in excess of background. The highest ^{60}Co concentrations occurred in sediment from the wide area of the discharge canal that consisted of clay minerals and organic matter of low density. Core samples indicated that ^{54}Mn and ^{60}Co were deposited to at least 6 cm, and possibly to 12 cm below the surface. The underwater probe proved to be useful for locating areas of radioactive buildup above 0.5 pCi ^{60}Co/g (see Section 5.7).

Except for a few elements, the ability to determine concentration factors (CF) was not possible at Oyster Creek. Water concentrations were generally undetectable and, except for barnacles, effluent concentrations were unuseable due to uncertainty in the amount of dilution occurring in Barnegat Bay with its complicated hydrology (see Section 5.1.1). In a few cases, however, it was possible to estimate CF's for this site when the concentrations were constant and measurable. In other cases, the magnitude of published CF's could be evaluated from measured sample concentrations and knowledge of station discharges. CF's derived from this study are

Element or radionuclide	Algae†	Grasses	Fish muscle	Fish whole	Clams	Whole barnacles
Fe	5000	6200	700	1850	ND*	ND
Sr	0.9	1.7	0.5	4	ND	1600**
Ca	1.4	1.9	1.8	19	ND	ND
K	14	10	15	11	7	ND
^{137}Cs	13	23	30	23	ND	100
^{54}Mn	ND	ND	ND	ND	< 1000	800
^{60}Co	ND	ND	ND	ND	600	1000

* ND – not determined

**Based on ^{90}Sr

† The average CF's for the three species of algae are given, but significant species differences were noted for K and ^{137}Cs

Published CF's of 100 and 600 for ^{60}Co and ^{54}Mn, respectively, in fish do not satisfy the observed data. The CF for ^{54}Mn is probably too high and may be nearer the value for ^{60}Co. Also, the CF for ^{54}Mn in clam meat was shown to be < 1000 rather than the published value of 12,000. The difficulties associated with the utilization of concentration factors are discussed in detail in Sections 5.4.4, 5.4.5, 5.5.3 and 5.5.4.

The highest population radiation doses from liquid discharges were computed from the annual average coolant canal concentrations to be from consuming fish caught in and near the coolant-water discharge canal. Fish consumption may result in 6 mrem/yr to bone, 0.9 mrem/yr to the GI tract, 1 mrem/yr to thyroid and 0.3 mrem/yr to the total body. These doses, although much greater than those based on measured radionuclide concentrations, are less than 5 percent of the limit recommended by the Federal Radiation Council and are almost entirely due to ^{32}P, ^{131}I and ^{133}I. These radionuclides were generally not determined with sufficient sensitivity or in sufficient samples of fish or clams to confirm the calculations and should, therefore, be measured (see Section 5.4.5). Naturally-occurring ^{210}Po is a major contributor to the total clam-ingestion dose, and, although its content in fish was not measured, a similar situation may apply to fish. It would be desirable to determine this radiation background dose from consuming seafood whenever the dose due to nuclear operations is evaluated.

7.3 Radionuclides in the Terrestrial Environment at the Oyster Creek Station

Gaseous radioactive effluents and direct radiation from the station were detected in the terrestrial environment. No samples of milk or food were obtained since they are not produced near the station in significant quantities due to poor soil conditions. The following measurements of radionuclides or radiation from the station in the environment were made:

(1) By collecting large volumes of air during routine stack discharge, ^{133}Xe was measured in ground-level air at concentrations ranging from 3×10^{-5} to 3×10^{-2} µCi/m^3, and ^{85}Kr at 3×10^{-4} µCi/m^3 (see Section 6.2.5). Other short-lived gases would have been detected if analysis was initiated promptly. The short-lived progeny of ^{88}Kr and ^{138}Xe were measured by drawing 133 m^3 of air through particulate filters and immediately analyzing them. Particulate or gaseous ^{131}I could not be detected during brief sampling periods although large volumes of air were sampled.

(2) Measurements of radioactive gases from the stack were made near the station with a muscle-equivalent ionization chamber, a pressurized ionization chamber and portable NaI(Tl) survey meters. The plume was readily detectable above the background radiation level. Computed radiation exposure rates at a location 1.5 km from the stack were two to three times higher than the measured rates (see Section 6.2.6).

(3) A muscle-equivalent ionization chamber mounted in a helicopter was used to measure radiation exposure rates in the plume of radioactive gases from the stack. This technique was shown to be useful in measuring the rise of the plume and its vertical and horizontal spreading. Exposure rates computed with models generally exceeded measured values (see Section 6.3).

(4) Direct radiation from station buildings measured with survey meters and a muscle-equivalent ionization chamber along the station boundary ranged up to 1.8 μR/hr (16 mR/yr) above the background radiation exposure of approximately 4.3 μR/hr (38 mR/yr). Extrapolation of elevated radiation exposure rates within the boundary to distant sites gives a result comparing well with measurements. The exposure rate at the nearest residence is estimated to be 0.08 mR/yr. The annual population dose to persons driving along Rt. 9, the eastern site boundary, is estimated to be 0.034 man-rem (see Section 6.4).

(5) Long-term radiation exposures in the station's environment were measured with thermoluminescent dosimeters. Measured levels above the natural radiation background were correlated with estimated exposures computed from a model (see Section 6.5).

7.4 Monitoring Procedures

The following procedures were demonstrated in this study for monitoring effluents and environments of BWR stations:

(1) analysis by gamma-ray spectrometry with Ge(Li) detectors of multiple radionuclides in samples of primary coolant and effluent water before discharge and dilution, and in off-gas from reactor coolant and in various airborne waste pathways;

(2) measurement of effluent radionuclides other than the long-lived ones readily detected by gamma-ray spectrometry; of particular interest, in addition to usually measured ^{3}H, ^{89}Sr and ^{90}Sr, are ^{14}C, ^{32}P and ^{55}Fe;

(3) collection of ionic and insoluble radionuclides in fresh and sea water by concentration from 400-liter volumes for measurements at concentrations as low as 10^{-10} μCi/ml;

(4) collection and analysis of food samples, including fish, clams and crabs;

(5) collection and analysis of environmental media that serve as indicators, including aquatic grasses, algae, barnacles and sediment;

(6) surveillance of sediment with submersible gamma-ray detectors to indicate "hot spots" for detailed sampling and analysis, and the superiority of sediment sampling by hand (diver) rather than by dredge;

(7) measurement of ^{3}H and ^{14}C in several gaseous species;

(8) use of portable 5- x 5-cm NaI(Tl) survey meters as sensitive detectors of the plume from the stack;

(9) use of muscle-equivalent ionization chamber and pressurized ionization chamber for quantifying the radiation exposure rate during brief periods within or beneath the plume;

(10) use of thermoluminescent dosimeters to quantify the average long-term radiation exposure rate from the plume;

(11) use of pressurized ionization chamber, large 15- x 23-cm NaI(Tl) detector and spectrometer, muscle-equivalent ionization chamber with Shonka electrometer, and a portable 5- x 5-cm NaI(Tl) survey meter to measure direct radiation from the station;

(12) use of helicopter to characterize plume shape and dispersion;

(13) collection of large volumes of environmental air and applying separation techniques for measurement of ^{133}Xe and ^{85}Kr at very low concentrations, (applicable also to short-lived noble gases);

(14) collection of ^{88}Rb and ^{138}Cs in environmental air on filters with high-volume samplers, and analysis by gamma-ray spectrometry; and

(15) use of measured release rates at the station, meteorological data and transfer coefficients to estimate radionuclide concentrations in samples for comparison with measured or minimum detectable values.

In addition, the following procedures were demonstrated in a previous study for monitoring environments of BWR stations:

(1) collection and analysis of drinking water and food samples, including vegetables, milk, rabbits and deer;

(2) collection of radioiodine from 22.5-liter volumes of milk on anion-exchange resin, and analysis by gamma-ray spectrometry; and

(3) use of bovine thyroids to detect ^{131}I at very low concentrations (equivalent to 0.02 pCi/liter milk) in the terrestrial environment.

7.5 Recommendations for Environmental Surveillance

The fundamental objective of an environmental surveillance program is to measure radiation dose rates and radionuclide concentrations in the critical exposure pathways in order to determine radiation doses to individuals and selected population groups from operation of a nuclear facility and to determine or confirm compliance with applicable standards. Other objectives are to confirm estimated environmental concentrations based on effluent data, determine any accumulation of long-lived radionuclides in the plant environs, and respond to public concerns and inquiries.

The recommendation for radiological surveillance programs conducted by nuclear generating stations to meet the above objectives, based on observations in this study and those at Dresden I BWR, and the Yankee and Haddam Neck PWR's, is that all radioactive effluents be analyzed to obtain in detail their radionuclide content. Environmental radionuclides and radiation levels attributable to station operation are generally too variable, obscured by the radiation background, or near instrumental detection limits to be measured with sufficient accuracy for evaluating exposure. The measurements at the source must include all significant pathways and radionuclides during the entire period of operation; critical radionuclides can be missed by monitoring only the obvious effluents and, as in the case of ^{32}P, the easily measured radionuclides, or by ignoring the effects of changes in the operating cycle. After all radionuclides in the effluent have been quantified and all critical pathways identified, analyses can be limited to the radionuclides at highest abundance and of greatest health significance in environmental samples from the critical pathways. Additional samples for analysis should include only media that are known or observed to concentrate radionuclides discharged by the station. As knowledge of the environment increases and the pattern of radionuclide discharges is established, fewer measurements will be needed. However, significant changes in station operation or radionuclide content of effluents will require at least a brief return to more detailed analysis.

The environmental program must be evaluated periodically to consider modification in response to changes in effluent radioactivity, new patterns of population distribution and environmental use, and increased knowledge of the behavior of radionuclides in the environment.

Adhering to these recommendations will insure a radiological surveillance program that will provide the necessary information to satisfy the above objectives at a lower cost than many current programs that include non-pathway type samples or samples that continually contain either less than measurable quantities or concentrations indiscernible from the natural radiation background. Also, the recommended program will generate on-site transfer coefficients and concentration factors providing a better and more pertinent basis for calculating exposures at the site from station effluent data than most published values.

Environmental measurements at the Oyster Creek Station were found to be useful in developing the environmental surveillance recommendations described above, for supporting and confirming the population radiation exposures computed from on-site monitoring, and for providing these computations with numerical factors applicable to the site. Such measurements, if performed reliably, can also be reassuring in demonstrating that no unexpected radioactivity is in the environment. For a station and site such as Oyster Creek, the following measurements provide useful information:

(1) confirmation of critical pathways
    a) measure inhalation and external radiation exposure rates from the plume at off-site locations,
    b) measure direct radiation exposure rates on site and the decrease of the exposure rate with distance to off-site locations,
    c) measure critical radionuclides in fish, clams and crabs caught in the intake and discharge canals and in Barnegat Bay;
(2) determination of numerical factors for computing radiation doses
    a) determine the soluble and insoluble radionuclide fractions in liquid effluents and in the discharge canal,
    b) confirm or ascertain applicability of aquatic concentration factors,
    c) compute χ/Q values by measuring ^{133}Xe or other radionuclide concentrations in ground-level air relative to the release rate at the station;
(3) utilization of environmental concentration loci
    a) measure critical radionuclides in marine grasses, algae and barnacles to determine the extent of contamination in the aquatic environment;
(4) assurance that no significant exposure exists from unforeseen sources or occasional operational occurrences
    a) measure radiation exposure at nearby habitations, canal banks utilized by fishermen and beaches in the immediate area,
    b) measure radionuclides in seafood and water collected from the immediate vicinity of the station.

c) if agricultural practices change in the vicinity of the station, measure radionuclides in milk and food products.

7.6 Suggested Future Studies

The following studies at nuclear facilities are suggested on the basis of the previous four field studies:

1) develop more sensitive techniques for measuring radioiodines in various chemical forms in airborne waste pathways through the station and in environmental air;
2) develop techniques to measure gaseous radionuclides, such as ^{83m}Kr and ^{131m}Xe that emit only low-energy photons, while being part of a noble gas mixture;
3) examine the effect of radioactive waste treatment on discharge practices in order to evaluate the cost of reducing the radionuclide content of effluents;
4) characterize the physical-chemical states of radionuclides in liquid wastes discharged to the environment and determine changes occurring after mixing with environmental waters;
5) measure critical radionuclides in environmental samples that are difficult to analyze, such as ^{32}P in Oyster Creek fish, to confirm hypothetical concentrations based on station effluent analysis;
6) perform a radiological surveillance study at a high temperature gas-cooled reactor (HTGR) similar to previous studies except focus effort on the gaseous effluents and their impact on the environment;
7) perform a surveillance study at a multiple reactor site to determine modeling parameters for dual stack releases and the existence of a scaling factor — quantities discharged vs power generation; and
8) perform studies to validate atmospheric dispersion models used in dose assessment at sites with different meteorological and topographical characteristics.

These studies will further determine the environmental impact of nuclear facilities and develop better environmental surveillance techniques.

Appendix A

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Appendix B.1

Oyster Creek Average Monthly Power and Reactor Coolant Chemistry Statistics from Semiannual Operating Reports

Period	MWe/hour (net output)	MWt/hour	pH
Jan. 1970		1330	
Feb.		756	
March		1593	
April		939	
May		395	
June		1274	
Jan.-June '70 Avg.	346	1052	
July 1970	480	1473	
Aug.	484	1550	
Sept.	403	1244	
Oct.	298	954	
Nov.	521	1567	
Dec.	476	1371	
July-Dec. '70 Avg.	442	1366	
Jan. 1971	504	1515	
Feb.	447	1347	
March	541	1606	
April	562	1677	
May	551	1671	
June	545	1685	
Jan.-June '71 Avg.	523	1580	6.3
July 1971	535	1687	
Aug.	525	1654	
Sept.	286	904	
Oct.	(1)	(1)	
Nov.	203	511	
Dec.	584	1702	
July-Dec. '71 Avg.	351	1087	6.0
Jan. 1972	545	1608	
Feb.	609	1735	
March	621	1807	
April	553	1625	
May	18	55	
June	155	376	
Jan.-June '72 Avg.	412	1228	6.1
July 1972	620	1885	
Aug.	458	1412	
Sept.	631	1885	
Oct.	645	1885	
Nov.	568	1651	
Dec.	548	1671	
July-Dec. '72 Avg.	579	1725	5.9
Jan. 1973	362	1058	
Feb.	607	1776	
March	635	1847	
April	269	778	
May	(1)	(1)	
June	392	1213	
Jan.-June '73 Avg.	368	1101	6.0

Period	MWe/hour (net output)	MWt/hour	Gross Beta (2 hrs μCi/ml)	^{3}H (μCi/ml)	^{131}I (μCi/g)	pH
July 1973	513	1428	0.41	3.8×10^{-3}	5.87×10^{-3}	6.1
Aug.	601	1838	0.39	4.4×10^{-3}	1.6×10^{-3}	6.1
Sept.	156	428	0.13	1.5×10^{-3}	5.59×10^{-3}	5.8
Oct.	322	1087	0.25	1.2×10^{-3}	0.81×10^{-3}	5.8
Nov.	524	1574	0.37	4.2×10^{-3}	2.85×10^{-3}	6.1
Dec.	609	1808	0.43	1.5×10^{-3}	0.9×10^{-3}	6.2
July-Dec. '73 Avg.	450	1377	0.37	2.9×10^{-3}	2.93×10^{-3}	6.0

(1) shutdown, no output.

Appendix B.2

Oyster Creek Radioactive Waste Discharges from Semiannual Operating Reports

	Liquid				Gaseous			
Period	Volume of liquid wastes (liters)	Gross β, γ (Ci)	Dissolved noble gases (Ci)	Tritium (Ci)	Noble gases (Ci)	Halogens* (Ci)	Particulate* (Ci)	Tritium (Ci)
May-Dec '69	3.27×10^7	0.48		5.07	0.70×10^4	< 0.01	0.08×10^{-2}	
Jan-June'70	2.55×10^7	7.2		10.35	4.35×10^4	0.13	0.32×10^{-2}	
July-Dec'70	2.67×10^7	11.2		11.51	6.83×10^4	0.18	0.67×10^{-2}	
Jan-June'71	1.46×10^7	8.81		9.87	17.49×10^4	0.70	2.11×10^{-2}	
July-Dec'71	0.94×10^7	3.31	1.25	11.59	34.15×10^4	1.33	8.90×10^{-2}	0.11
Jan-June'72	0.74×10^7	0.87	1.21	22.82	60.62×10^4	2.76	8.40×10^{-2}	0.24
July-Dec'72	0.85×10^7	9.16	2.08	38.79	26.01×10^4	3.50	14.60×10^{-2}	0.52
Jan-June'73	0.58×10^7	1.07	1.26	16.99	63.16×10^4	4.90	24.20×10^{-2}	0.15
July-Dec'73	0.65×10^7	3.08	1.71	19.63	18.08×10^4	1.83	18.08×10^{-2}	0.17
July '71	0.79×10^6	0.12	0.22	0.78	6.22×10^4	0.30	0.7×10^{-2}	0.03
Aug. '71	0.85×10^6	0.11	0.25	1.02	10.66×10^4	0.28	1.9×10^{-2}	0.03
Sept. '71	0.85×10^6	0.05	0.20	0.98	6.75×10^4	0.10	1.3×10^{-2}	0.02
Oct. '71	3.08×10^6	0.41	< 0.01	3.60	0	0	$< 0.1 \times 10^{-2}$	0
Nov. '71	2.74×10^6	0.72	0.31	3.55	0.86×10^4	0.16	1.4×10^{-2}	0.01
Dec. '71	1.14×10^6	1.90	0.28	1.65	9.66×10^4	0.49	3.5×10^{-2}	0.03
Jan. '72	1.17×10^6	0.08	0.27	1.73	11.5×10^4	0.42	1.3×10^{-2}	0.03
Feb. '72	1.27×10^6	0.08	0.35	3.11	12.78×10^4	0.51	1.1×10^{-2}	0.06
March '72	0.98×10^6	0.17	0.33	3.06	16.73×10^4	0.54	1.9×10^{-2}	0.05
April '72	0.38×10^6	0.03	0.11	0.84	18.09×10^4	0.71	1.6×10^{-2}	0.05
May '72	1.55×10^6	0.24	< 0.01	5.06	0.82×10^4	0.39	1.4×10^{-2}	0.00
June '72	2.02×10^6	0.27	0.15	9.02	0.70×10^4	0.18	1.1×10^{-2}	0.04
July '72	2.08×10^6	1.23	0.52	10.52	2.13×10^4	0.30	1.3×10^{-2}	0.11
Aug. '72	2.55×10^6	5.05	0.66	12.33	2.41×10^4	0.49	1.2×10^{-2}	0.12
Sept. '72	1.67×10^6	2.09	0.40	8.36	3.34×10^4	0.53	1.1×10^{-2}	0.06
Oct. '72	1.05×10^6	0.63	0.25	5.19	4.30×10^4	0.77	1.2×10^{-2}	0.08
Nov. '72	0.44×10^6	0.05	0.08	< 0.01	4.91×10^4	0.64	6.4×10^{-2}	0.06
Dec. '72	0.69×10^6	0.11	0.18	2.39	8.41×10^4	0.78	3.4×10^{-2}	0.08
Jan. '73	0.81×10^6	0.19	0.07	2.38	5.00×10^4	0.93	1.4×10^{-2}	0.03
Feb. '73	0.77×10^6	0.20	0.28	2.37	15.07×10^4	0.82	12.0×10^{-2}	0.03
March '73	1.14×10^6	0.18	0.48	3.46	29.02×10^4	1.11	5.0×10^{-2}	0.04
April '73	1.05×10^6	0.23	0.37	3.06	12.18×10^4	1.44	2.8×10^{-2}	0.02
May '73	1.79×10^6	0.18	< 0.01	4.98	0	0.06	0.3×10^{-2}	0
June '73	0.27×10^6	0.09	0.05	0.72	1.89×10^4	0.54	2.7×10^{-2}	0.03
July '73	1.49×10^6	0.99	0.55	4.68	3.30×10^4	0.49	1.8×10^{-2}	0.07
Aug. '73	1.38×10^6	0.84	0.48	4.31	5.03×10^4	0.65	3.8×10^{-2}	0.02
Sept. '73	1.72×10^6	0.56	0.28	5.13	0.70×10^4	0.15	3.6×10^{-2}	0.01
Oct '73	1.26×10^6	0.36	0.20	3.66	1.66×10^4	0.21	2.1×10^{-2}	0.02
Nov. '73	0.29×10^6	0.12	0.08	0.67	3.12×10^4	0.20	4.1×10^{-2}	0.02
Dec. '73	0.41×10^6	0.23	0.13	0.97	4.08×10^4	0.13	2.7×10^{-2}	0.03

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* half life >8 days

Appendix B.3

Oyster Creek Noble Gas Discharges from Semiannual Operating Reports

	Discharge, Ci					
Period	^{85m}Kr	^{87}Kr	^{88}Kr	^{133}Xe	^{135}Xe	^{138}Xe
July-Dec. 1971	3.37×10^4	3.93×10^4	6.57×10^4	7.17×10^4	1.11×10^5	2.04×10^4
Jan.-June 1972	4.58×10^4	1.05×10^5	1.40×10^5	1.12×10^4	1.59×10^5	4.40×10^4
July-Dec. 1972	1.97×10^4	4.42×10^4	6.01×10^4	3.84×10^4	7.20×10^4	2.57×10^4
Jan.-June 1973	4.79×10^4	9.88×10^4	1.55×10^5	9.50×10^4	1.86×10^5	4.88×10^4
July-Dec. 1973	1.16×10^4	3.46×10^4	3.99×10^4	3.11×10^4	3.47×10^4	2.89×10^4

Appendix B.4a

Radionuclides Discharged in Liquid Wastes by the Oyster Creek Nuclear Generating Station, 1971

Nuclide	Discharged 1/1-6/30,* Ci(1)	Conc. in Oyster Creek 1/1-6/30, pCi/l	Discharged, Ci(2)						Concentrations in Oyster Creek, pCi/liter**						Average Concentration 7/1-12/31, pCi/l
			July	Aug	Sept	Oct	Nov	Dec	July	Aug	Sept	Oct	Nov	Dec	
^{3}H	9.87	21.0	0.78	1.02	0.98	3.60	3.55	1.65	6.55	8.95	11.36	41.91	39.23	19.30	21.22
^{32}P	NR+	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{51}Cr	0.080	0.17	0.017	0.040	ND	ND	0.026	0.001	0.14	0.35	ND	ND	0.29	0.012	0.13
^{54}Mn	0.029	0.062	0.001	0.001	0.002	0.054	0.152	0.192	0.0084	0.0088	0.023	0.63	1.68	2.25	0.77
^{58}Co	0.0070	0.015	<0.001	<0.001	0.001	0.014	0.038	0.048	<0.0084	0.0088	0.012	0.16	0.42	0.56	0.19
^{60}Co	0.057	0.12	0.003	0.003	0.005	0.090	0.256	0.409	0.025	0.026	0.058	1.05	2.83	4.78	1.46
^{59}Fe	0.043	0.096	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{65}Zn	<0.005	<0.011	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{89}Sr	0.104	0.22	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{90}Sr			0.002	0.001	0.007	0.135	0.022	0.072	0.017	0.0088	0.081	1.57	0.24	0.84	0.46
^{91}Sr	NR	NR	ND+	ND	ND	ND	ND	0.050	ND	ND	ND	ND	ND	0.58	0.10
^{99}Mo	0.026	0.055	0.038	0.018	0.001	<0.001	0.003	0.043	0.32	0.16	0.012	<0.012	0.033	0.50	0.17
^{99m}Tc	0.026	0.055	0.010	0.007	0.002	0.002	0.005	0.049	0.084	0.061	0.023	0.023	0.055	0.57	0.14
^{124}Sb	NR	NR	ND	ND	ND	ND	0.001	0.002	ND	ND	ND	ND	0.011	0.023	0.006
^{131}I	0.113	0.25	0.007	0.009	0.026	0.063	0.018	0.144	0.059	0.079	0.30	0.73	0.20	1.68	0.51
^{133}I	0.0044	0.010	0.005	0.010	0.004	<0.001	0.086	0.182	0.042	0.088	0.046	<0.012	0.95	2.13	0.54
^{134}Cs	0.072	0.15	ND	ND	ND	0.008	0.017	0.004	ND	ND	ND	0.093	0.19	0.047	0.055
^{137}Cs	0.116	0.25	ND	ND	ND	0.034	0.041	0.051	ND	ND	ND	0.40	0.45	0.60	0.24
$^{140}Ba/La$	0.054	0.12	0.024	0.007	ND	0.005	0.013	0.057	0.20	0.061	ND	0.058	0.16	0.66	0.19
^{239}Np	NR	NR	0.014	0.011	0.002	0.002	0.035	0.592	0.12	0.096	0.023	0.023	0.39	6.92	1.26
Vol. of wastes (liters)	1.46×10^{7}		7.91×10^{5}	8.52×10^{5}	8.44×10^{5}	3.08×10^{6}	2.74×10^{6}	1.14×10^{6}							
Total dilution (liters)	4.70×10^{11}		1.19×10^{11}	1.14×10^{11}	8.63×10^{10}	8.59×10^{10}	9.05×10^{10}	8.55×10^{10}							

* Reported semiannual totals
**No correction for recirculation has been included
+ NR - not reported, ND - not detected

Notes:

1) Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - January 1, 1971 to June 30, 1971," Semi-Annual Rept. #4

2) Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - July 1, 1971 to December 31, 1971," Semi-Annual Rept. #5

Appendix B.4b

Radionuclides Discharged in Liquid Wastes by the Oyster Creek Nuclear Generating Station, Jan.-June 1972

Nuclide	Discharged, Ci$^{(1)}$						Concentration in Oyster Creek, pCi/liter*						Average Concentration, pCi/l
	Jan	Feb	March	April	May	June	Jan.	Feb.	March	April	May	June	
^{3}H	1.73	3.11	3.06	0.84	5.06	9.02	23.19	35.10	31.45	8.88	63.09	110.81	45.42
^{32}P	NR^{+}	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{51}Cr	ND^{+}	ND	0.008	0.006	0.038	0.001	ND	ND	0.082	0.063	0.47	0.012	0.10
^{54}Mn	0.017	0.004	0.005	<0.001	0.028	0.030	0.23	0.045	0.051	<0.011	0.35	0.37	0.18
^{58}Co	0.004	0.001	0.001	<0.001	0.008	0.007	0.054	0.011	0.010	<0.011	0.100	0.086	0.045
^{60}Co	0.041	0.012	0.009	0.003	0.050	0.053	0.55	0.14	0.092	0.032	0.62	0.65	0.35
^{59}Fe	ND	ND	ND	ND	0.020	ND	ND	ND	ND	ND	0.25	ND	0.042
^{65}Zn	<0.003	<0.003	<0.002	<0.001	<0.004	<0.005	<0.04	<0.034	<0.021	<0.011	<0.050	<0.061	<0.036
^{89}Sr ^{90}Sr	0.002	0.002	0.027	0.013	0.052	0.066	0.027	0.023	0.28	0.14	0.62	0.81	0.32
^{91}Sr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{99}Mo	0.006	0.012	0.006	0.002	0.002	0.011	0.080	0.14	0.062	0.021	0.025	0.14	0.078
^{99m}Tc	0.006	0.012	0.006	0.002	0.002	0.011	0.080	0.14	0.062	0.021	0.025	0.14	0.078
^{124}Sb	ND	ND	ND	ND	0.002	<0.001	ND	ND	ND	ND	0.025	0.012	0.0062
^{131}I	0.005	0.021	0.035	0.001	0.016	0.023	0.067	0.24	0.36	0.011	0.20	0.28	0.19
^{133}I	0.003	0.011	0.018	<0.001	ND	0.037	0.040	0.12	0.18	<0.011	ND	0.45	0.13
^{134}Cs	<0.001	0.001	0.020	<0.001	0.003	0.012	<0.013	0.011	0.21	<0.011	0.037	0.15	0.070
^{137}Cs	<0.001	<0.001	0.034	ND	0.003	0.013	<0.013	<0.011	0.35	ND	0.037	0.16	0.093
^{140}Ba/La	ND	ND	ND	ND	0.016	0.002	ND	ND	ND	ND	0.20	0.025	0.038
^{239}Np	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{95}Zr-^{95}Nb	ND	ND	ND	ND	<0.001	ND	ND	ND	ND	ND	<0.012	ND	<0.002
Vol. of wastes (liters)	1.17×10^{6}	1.26×10^{6}	9.80×10^{5}	3.82×10^{5}	1.55×10^{6}	2.02×10^{6}							
Total dilution (liters)	7.46×10^{10}	8.86×10^{10}	9.73×10^{10}	9.46×10^{10}	8.02×10^{10}	8.14×10^{10}							

* No correction for recirculation has been included

$^{+}$ NR - not reported, ND - not detected

Note:

1) Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - January 1, 1972-June 30, 1972," Semi-Annual Rept. #6

Appendix B.4c

Radionuclides Discharged in Liquid Wastes by the Oyster Creek Nuclear Generating Station, July-Dec. 1972

Nuclide	Discharged, Ci(1)						Concentration in Oyster Creek, pCi/l[*]						Average Concentration, pCi/l
	July	Aug	Sept	Oct	Nov	Dec	July	Aug.	Sept	Oct	Nov	Dec	
^{3}H	10.5	12.3	8.4	5.2	0.001	2.4	87.5	102.5	72.4	43.7	0.011	31.3	56.23
^{51}Cr	0.036	0.022	ND[+]	ND	ND	0.007	0.30	0.18	ND	ND	ND	0.09	0.10
^{54}Mn	0.041	0.193	0.252	0.046	0.002	0.011	0.34	1.61	2.17	0.39	0.023	0.14	0.78
^{58}Co	0.010	0.046	0.059	0.012	<0.001	0.003	0.083	0.383	0.509	0.101	<0.011	0.039	0.19
^{60}Co	0.094	0.369	0.853	0.161	0.008	0.023	0.783	3.075	7.353	1.353	0.091	0.300	2.16
^{59}Fe	NR[+]	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{65}Zn	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
^{89}Sr ^{90}Sr	0.058	0.002	0.002	0.001	<0.001	0.002	0.483	0.017	0.017	0.008	<0.011	0.026	0.093
^{91}Sr	ND	0.006	0.014	0.045	ND	ND	ND	0.050	0.121	0.378	ND	ND	0.092
^{99}Mo	0.037	0.055	0.035	0.029	0.006	0.014	0.308	0.458	0.302	0.244	0.068	0.182	0.26
^{99m}Tc	0.037	0.039	0.035	0.029	0.006	0.014	0.308	0.325	0.302	0.244	0.068	0.182	0.24
^{124}Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{131}I	0.042	0.161	0.085	0.053	0.005	0.005	0.350	1.342	0.733	0.445	0.057	0.065	0.50
^{133}I	0.103	0.096	0.064	0.072	0.003	0.006	0.858	0.800	0.552	0.605	0.034	0.078	0.49
^{134}Cs	0.292	1.376	0.285	0.059	0.004	0.008	2.433	11.467	2.457	0.496	0.045	0.104	2.83
^{137}Cs	0.440	2.058	0.402	0.077	0.008	0.010	3.67	17.15	3.47	0.65	0.091	0.130	4.19
^{140}Ba-La	0.008	0.037	ND	<0.001	<0.001	0.002	0.067	0.308	ND	<0.008	<0.011	0.026	0.069
^{239}Np	0.031	0.589	0.005	0.046	0.005	0.007	0.258	4.908	0.043	0.387	0.057	0.091	0.96
Vol. of wastes (liters)	2.08×10^{6}	2.54×10^{6}	1.67×10^{6}	1.05×10^{6}	4.35×10^{5}	6.93×10^{5}							
Total dilution (liters)	1.20×10^{11}	1.20×10^{11}	1.16×10^{11}	1.19×10^{11}	8.80×10^{10}	7.67×10^{10}							

[*] No correction for recirculation has been included

[+] NR - not reported; ND - not detected

Note

1. Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - July 1, 1972 to December 31, 1972," Semi-Annual Report #7.

Appendix B.4d

Radionuclides Discharged in Liquid Wastes by the Oyster Creek Nuclear Generating Station, Jan.-June 1973

Nuclide	Discharged, Ci (1)						Concentration in Oyster Creek, pCi/l*						Average Concentration, pCi/l
	Jan	Feb	March	April	May	June	Jan	Feb	March	April	May	June	
^{3}H	2.385	2.371	3.461	3.064	4.980	0.724	30.70	32.48	44.54	33.74	56.78	6.47	34.12
^{51}Cr	ND+	0.003	0.039	0.054	0.026	0.022	ND	0.041	0.50	0.60	0.30	0.20	0.27
^{54}Mn	0.028	0.020	0.001	0.003	0.016	0.012	0.36	0.27	0.013	0.033	0.18	0.11	0.16
^{59}Fe	ND	ND	ND	<0.001	ND	ND	ND	ND	ND	<0.011	ND	ND	<0.011
^{58}Co	0.006	0.005	<0.001	0.001	0.003	0.002	0.077	0.069	<0.013	0.011	0.034	0.018	0.036
^{60}Co	0.026	0.041	0.004	0.008	0.024	0.013	0.34	0.56	0.052	0.088	0.27	0.12	0.24
^{65}Zn	ND	ND	ND	0.001	ND	ND	ND	ND	ND	0.011	ND	ND	<0.011
^{89}Sr	0.002	0.014	0.025	0.023	0.044	0.008	0.026	0.19	0.32	0.25	0.50	0.054	0.22
^{90}Sr	<0.001	0.002	0.004	0.004	0.008	0.001	0.013	0.027	0.052	0.044	0.091	0.009	0.039
^{91}Sr	ND	ND	ND	0.001	<0.001	ND	ND	ND	ND	0.011	<0.011	ND	0.003
^{91}Y	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND	ND	0.018	0.003
^{99}Mo	0.010	0.015	0.034	0.028	0.003	0.008	0.13	0.21	0.44	0.29	0.034	0.054	0.19
^{99m}Tc	0.010	0.015	0.034	0.028	0.002	0.008	0.13	0.21	0.44	0.29	0.023	0.054	0.19
^{124}Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{131}I	0.016	0.001	0.004	0.032	0.012	0.001	0.21	0.014	0.052	0.35	0.14	<0.009	0.13
^{133}I	0.006	0.002	0.004	0.008	0.001	0.001	0.077	0.027	0.052	0.088	<0.011	0.009	0.043
^{133}Xe	0.019	0.071	0.075	0.181	0.005	0.010	0.25	0.97	0.97	1.99	0.057	0.089	0.72
^{135}Xe	0.050	0.214	0.402	0.193	ND	0.039	0.64	2.93	3.17	2.13	ND	0.35	1.87
^{134}Cs	0.020	0.005	0.004	0.005	0.006	0.001	0.26	0.069	0.052	0.055	0.068	0.009	0.088
^{137}Cs	0.029	0.004	0.002	0.002	0.006	0.001	0.37	0.055	0.026	0.022	0.068	0.009	0.092
^{140}Ba-La	0.006	0.012	0.010	0.024	0.005	0.002	0.077	0.16	0.13	0.26	0.057	0.018	0.12
^{141}Ce	ND	ND	ND	ND	0.003	0.001	ND	ND	ND	ND	0.034	0.009	0.007
^{144}Ce	ND	ND	ND	ND	0.015	0.002	ND	ND	ND	ND	0.17	0.018	0.031
^{239}Np	0.033	0.060	0.014	0.015	0.001	0.007	0.43	0.82	0.18	0.17	0.011	0.063	0.28
Vol. of wastes (liters)	8.06×10^{5}	7.65×10^{5}	11.43×10^{5}	10.52×10^{5}	17.94×10^{5}	2.69×10^{5}							
Total dilution (liters)	7.77×10^{10}	7.30×10^{10}	7.77×10^{10}	9.08×10^{10}	8.77×10^{10}	11.19×10^{10}							

*No correction for recirculation has been included

+ND - not detected

Note:

1. Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - January 1, 1973 to June 30, 1973," Semi-Annual Rept #8.

Appendix B.4e

Radionuclides Discharged in Liquid Wastes by the Oyster Creek Nuclear Generating Station, July-Dec. 1973

Nuclide	Discharged, Ci$^{(1)}$						Concentration in Oyster Creek, pCi/1*						Average Concentration, pCi/1
	July	Aug	Sept	Oct.	Nov.	Dec.	July	Aug.	Sept	Oct.	Nov	Dec.	
^{3}H	4.676	4.310	5.130	3.860	0.668	0.974	39.04	35.50	55.04	34.35	6.27	8.21	29.74
^{51}Cr	0.106	0.079	0.087	0.049	0.012	0.012	0.89	0.65	0.93	0.44	0.11	0.10	0.52
^{54}Mn	0.042	0.013	0.027	0.008	<0.001	0.001	0.35	0.11	0.29	0.071	<0.009	0.008	0.14
^{59}Fe	<0.001	0.005	ND†	0.004	<0.001	ND	<0.008	0.041	ND	0.036	<0.009	ND	0.014
^{58}Co	0.011	0.004	0.006	0.002	<0.001	<0.001	0.092	0.033	0.064	0.018	<0.009	<0.008	0.036
^{60}Co	0.045	0.037	0.057	0.011	0.003	0.003	0.38	0.31	0.61	0.098	0.028	0.075	0.24
^{65}Zn	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{89}Sr	0.046	0.015	0.004	<0.001	0.001	<0.001	0.38	0.12	0.043	<0.009	<0.009	<0.008	0.09
^{90}Sr	0.001	0.003	<0.001	0.001	0.001	<0.001	0.0084	0.025	<0.011	<0.009	<0.009	<0.008	0.009
^{91}Sr	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{91}Y	0.008	0.002	ND	0.008	ND	ND	0.067	0.016	ND	0.071	ND	ND	0.026
^{99}Mo	0.048	0.046	0.020	0.018	0.007	0.010	0.40	0.38	0.22	0.15	0.07	0.08	0.22
^{99m}Tc	0.048	0.046	0.020	0.018	0.007	0.010	0.40	0.38	0.22	0.16	0.07	0.08	0.22
^{124}Sb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
^{131}I	<0.001	0.002	0.011	0.001	ND	0.001	<0.008	0.017	0.118	0.009	ND	0.008	0.026
^{133}I	0.002	0.005	0.010	0.005	ND	0.034	0.017	0.041	0.107	0.045	ND	0.287	0.083
^{133}Xe	0.141	0.116	0.073	0.031	0.009	0.023	1.18	0.96	0.78	0.28	0.08	0.19	0.58
^{135}Xe	0.413	0.369	0.202	0.160	0.067	0.106	3.45	3.04	2.17	1.48	0.63	0.89	1.94
^{134}Cs	0.003	0.022	0.011	0.003	<0.001	0.002	0.025	0.181	0.118	0.027	<0.009	0.017	0.062
^{137}Cs	0.002	0.031	0.001	0.004	<0.001	<0.001	0.017	0.255	0.011	0.035	<0.009	0.008	0.055
^{140}Ba-La	0.034	0.022	0.010	0.012	0.004	0.006	0.28	0.18	0.11	0.11	0.04	0.05	0.13
^{141}Ce	ND	ND	0.001	ND	ND	ND	ND	ND	0.011	ND	ND	ND	0.002
^{144}Ce	ND	ND	0.003	ND	ND	ND	ND	ND	0.032	ND	ND	ND	0.005
^{239}Np	0.037	0.019	0.014	0.015	ND	0.018	0.31	0.16	0.15	0.13	ND	0.15	0.15
Vol. of wastes (liters)	1.490×10^{6}	1.379×10^{6}	1.720×10^{6}	1.265×10^{6}	0.288×10^{6}	0.406×10^{6}							
Total dilution (liters)	11.977×10^{10}	12.141×10^{10}	9.320×10^{10}	11.235×10^{10}	10.659×10^{10}	11.860×10^{10}							

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*No correction for recirculation has been included.

†ND - not detected

Note

1 Jersey Central Power & Light Company, "Oyster Creek Nuclear Generating Station, Report of Operations - July 1, 1973 to December 31, 1973," Semi-Annual Report #9.

Appendix C.1

Calculated Generation Rate of Fission Products in Fuel at 1930 MWt Power

Fission Product	Yield, $y^{(b)}$	Decay constant λ, s^{-1}	Generation rate μCi/s	Accumulation in 700 days, μCi
^{3}H	$9.5 \times 10^{-5(c)}$	1.78×10^{-9}	2.2×10^{2}	1.3×10^{10}
^{83m}Kr	5.8×10^{-3}	1.04×10^{-4}	7.7×10^{8}	7.5×10^{12}
^{85m}Kr	1.3×10^{-2}	4.30×10^{-5}	7.2×10^{8}	1.7×10^{13}
^{85}Kr	2.9×10^{-3}	2.05×10^{-9}	7.6×10^{3}	4.4×10^{11}
^{87}Kr	2.4×10^{-2}	1.51×10^{-4}	4.8×10^{9}	3.1×10^{13}
^{88}Kr	3.5×10^{-2}	6.88×10^{-5}	3.2×10^{9}	4.5×10^{13}
^{89}Kr	4.2×10^{-2}	3.66×10^{-3}	2.0×10^{11}	5.4×10^{13}
^{89}Sr	4.5×10^{-2}	1.57×10^{-7}	9.1×10^{6}	5.8×10^{13}
^{90}Sr	5.5×10^{-2}	7.82×10^{-10}	5.5×10^{4}	3.3×10^{12}
^{95}Zr	6.4×10^{-2}	1.25×10^{-7}	1.0×10^{7}	8.3×10^{13}
^{95}Nb	6.4×10^{-2}	2.29×10^{-7}	$2.2 \times 10^{7(d)}$	1.8×10^{14}
^{99}Mo	5.7×10^{-2}	2.90×10^{-6}	2.1×10^{8}	7.4×10^{13}
^{103}Ru	3.3×10^{-2}	2.03×10^{-7}	8.7×10^{6}	4.3×10^{13}
^{124}Sb	3.0×10^{-7}	1.33×10^{-7}	5.2×10^{1}	3.9×10^{8}
^{131}I	3.2×10^{-2}	9.96×10^{-7}	4.1×10^{7}	4.1×10^{13}
^{133}I	6.5×10^{-2}	9.21×10^{-6}	7.7×10^{8}	8.4×10^{13}
^{135}I	6.0×10^{-2}	2.87×10^{-5}	2.2×10^{9}	7.7×10^{13}
^{131m}Xe	4.5×10^{-4}	6.74×10^{-7}	3.9×10^{5}	5.8×10^{11}
^{133m}Xe	1.9×10^{-3}	3.57×10^{-6}	8.6×10^{6}	2.5×10^{12}
^{133}Xe	6.5×10^{-2}	1.52×10^{-6}	1.3×10^{8}	8.4×10^{13}
^{135m}Xe	1.1×10^{-2}	7.38×10^{-4}	1.0×10^{10}	1.4×10^{13}
^{135}Xe	6.3×10^{-2}	2.10×10^{-5}	1.7×10^{9}	8.1×10^{13}
^{137}Xe	6.0×10^{-2}	3.02×10^{-3}	2.3×10^{11}	7.7×10^{13}
^{138}Xe	5.8×10^{-2}	8.15×10^{-4}	6.1×10^{10}	7.5×10^{13}
^{134}Cs	1.2×10^{-7}	1.06×10^{-8}	$\sim 4 \times 10^{4(e)}$	$\sim 1.6 \times 10^{12(e)}$
^{136}Cs	1.6×10^{-4}	6.17×10^{-7}	1.3×10^{5}	2.1×10^{11}
^{137}Cs	6.2×10^{-2}	7.30×10^{-10}	5.8×10^{4}	3.4×10^{12}
^{140}Ba	6.0×10^{-2}	6.26×10^{-7}	4.9×10^{7}	7.7×10^{13}
^{141}Ce	6.0×10^{-2}	2.48×10^{-7}	1.9×10^{7}	7.7×10^{13}
^{144}Ce	$5. \times 10^{-2}$	2.82×10^{-8}	1.9×10^{6}	5.5×10^{13}

[a] Based on 100% uranium fission; actually there is an increasing fraction with time related to the fission of generated plutonium.

[b] Meek, M. E. and B. F. Rider, "Compilation of Fission Product Yields," General Electric, Vallecitos Nuclear Center Rept. NEDO-12154-1 (1974).

[c] Albenesius, E. L. and R. S. Ondrejcin, "Nuclear-Fission Produces Tritium," Nucleonics 18 (9), 199 (1960).

[d] Equilibrium with longer-lived parent is assumed.

[e] Mountain, J. E., L. E. Eckart and J. H. Leonard, "Survey of Individual Radionuclide Production in Water-Cooled Reactors," University of Cincinnati Rept. (1968).

Notes:

1. $$\text{Generation rate} = \text{thermal power} \times \frac{\text{fission rate}}{\text{MWt}} \times \text{use factor} \times y \times \lambda =$$
   $$1930\ \text{MWt} \times \frac{3.1 \times 10^{16}\ \text{fission/s}}{\text{MWt}} \times 0.8 \times y \times \lambda \times \frac{\mu\text{Ci}}{3.7 \times 10^{4}\ \text{dis/s}}$$
2. A use factor of 0.8 was assumed typical.
3. $$\text{Accumulation} = \text{thermal power} \times \frac{\text{fission rate}}{\text{MWt}} \times \text{use factor} \times y\ (1-e^{-\lambda t})$$

Appendix D.1

Concentrations of Radioactive Gas Effluents from Main Condenser Steam Jet Air Ejectors after Passage Through 75-minute Delay Line

Radionuclide	Concentration, μCi/cc					Average concentration, μCi/cc
	Aug. 31, 1971	Jan. 18-20, 1972	Feb. 29, 1972	Apr. 10-12, 1972	Mar. 28, 1973	
10.0 -min ^{13}N	NM	4×10^{-4}	NM	NM	NM	4×10^{-4}
4.4 -hr ^{85m}Kr	9.1×10^{-2}	5.6×10^{-2}	5.8×10^{-2}	7.6×10^{-2}	1.9×10^{-1}	9.4×10^{-2}
10.76-yr ^{85}Kr	NM	9×10^{-5}	1×10^{-4}	1×10^{-5}	5.1×10^{-4}	1.9×10^{-4}
76.4 min ^{87}Kr	2.0×10^{-1}	1.2×10^{-1}	1.0×10^{-1}	1.4×10^{-1}	3.6×10^{-1}	1.8×10^{-1}
2.8 -hr ^{88}Kr	1.5×10^{-1}	1.1×10^{-1}	1.0×10^{-1}	1.3×10^{-1}	5.2×10^{-1}	2.0×10^{-1}
8.05-d ^{131}I	NM	2.5×10^{-6}	4.0×10^{-6}	4.0×10^{-6}	7.6×10^{-8}	2.6×10^{-6}
2.26-d ^{133m}Xe	1.1×10^{-2}	2.9×10^{-3}	2.5×10^{-3}	4.5×10^{-3}	1.8×10^{-2}	7.8×10^{-3}
5.27-d ^{133}Xe	3.0×10^{-1}	1.8×10^{-1}	1.8×10^{-1}	2.5×10^{-1}	4.5×10^{-1}	2.7×10^{-1}
15.6 -min ^{135m}Xe	1.1×10^{-1}	3.1×10^{-2}	2.7×10^{-2}	3.5×10^{-1}	1.1×10^{-1}	1.3×10^{-1}
9.16-hr ^{135}Xe**	3.8×10^{-1}	2.7×10^{-1}	2.6×10^{-1}	NM	9.7×10^{-1}	4.7×10^{-1}
14.2 -min ^{138}Xe	7.0×10^{-2}	4.0×10^{-2}	4.7×10^{-2}	NM	1.7×10^{-1}	8.2×10^{-2}
Gross radioactivity release rate, μCi/s						
Plant report	3.6×10^{4}	4.7×10^{4}	No data	7.8×10^{4}	1.2×10^{5}	
HASL measurement	6.1×10^{4}	3.6×10^{4}	3.5×10^{4}	4.5×10^{4}	1.2×10^{5}	

* Beck, H. et al., U. S. Atomic Energy Commission, personal communications, July 1972 and H. Beck, April 16, 1973.

** Includes decay of ^{135m}Xe.

NM - not measured.

Appendix D.2

Release Rates and Estimated Annual Discharges of Radioactive Gases from Main Condenser Air Ejector Delay Line

Radionuclide	Average release rate during sampling,** μCi/s	Normalized avg. release rate,+ μCi/s	Estimated annual release,++ Ci
^{13}N	2×10^{1}	2×10^{1}	5×10^{2}
^{85m}Kr	4.2×10^{3}	2.7×10^{3}	6.9×10^{4}
^{85}Kr	8.6	5.6	1.4×10^{2}
^{87}Kr	8.4×10^{3}	5.2×10^{3}	1.3×10^{5}
^{88}Kr	9.1×10^{3}	5.7×10^{3}	1.4×10^{5}
^{131}I	1.2×10^{-1}	6.6×10^{-2}	1.7
^{133m}Xe	3.5×10^{2}	2.2×10^{2}	5.5×10^{3}
^{133}Xe	1.2×10^{4}	7.6×10^{3}	1.9×10^{5}
^{135m}Xe	5.6×10^{3}	3.5×10^{3}	8.8×10^{4}
^{135}Xe	2.0×10^{4}	1.3×10^{4}	3.3×10^{5}
^{138}Xe	3.6×10^{3}	2.4×10^{3}	6.0×10^{4}

[*] Computed from data given in Appendix D.1.

[**] Based on delay line off-gas flow rates of 4.5×10^{4} cc/s (95 cfm).

[+] Average of gross radioactivity stack release rates during sampling normalized to annual average stack release rate of 3.90×10^{4} μCi/s reported by plant for period of July 1, 1971 to June 30, 1973.

[++] Based on 292 days (2.52×10^{7} s) of reactor operation per year.

Appendix D.3

Release Rates and Estimated Annual Discharges of Noble Gases in Turbine Gland Seal Condenser Off-Gas, February 29, 1972

Radionuclide	Release rate,** µCi/s	Estimated annual release,+ Ci
^{85m}Kr	2.9	8.2×10^{1}
^{87}Kr	1.03×10^{1}	2.9×10^{2}
^{88}Kr	5.1	1.4×10^{2}
^{133}Xe	7.5	2.1×10^{2}
^{135m}Xe	4.2×10^{1}	1.2×10^{3}
^{135}Xe	1.65×10^{1}	4.7×10^{2}
^{138}Xe	7.15×10^{1}	2.0×10^{3}

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[*] Beck, H. et al., U. S. Atomic Energy Commission, personal communication, July 1972.

[**] Based on off-gas release rate of 2.8×10^5 cc/s (600 cfm). Gross radioactivity release rate was 3.47×10^4 µCi/s on February 29, 1972.

[+] Calculated for an annual average stack release rate of gross radioactivity of 3.90×10^4 µCi/s during reactor operation and 292 days (2.52×10^7 s).

Appendix D.4

Release Rates of Gaseous Radionuclides from End of Steam Condenser Air Ejector Delay Line and in Stack, µCi/s

Radionuclide	Jan. 1972** Delay Line	Jan. 1972** Stack	Mar. 28, 1973+ Delay Line	Mar. 28, 1973+ Stack
^{85m}Kr	2.6×10^3	2.0×10^3	8.8×10^3	8.9×10^3
^{85}Kr	6	6	2.7×10^1	NM
^{87}Kr	4.4×10^3	4.9×10^3	1.60×10^4	1.59×10^4
^{88}Kr	4.4×10^3	4.9×10^3	2.3×10^4	2.0×10^4
^{89}Kr	---	---	0	0
^{133m}Xe	---	---	8×10^2	9×10^2
^{133}Xe	8.0×10^3	7.9×10^3	$\sim 2.0 \times 10^4$	2.02×10^4
^{135m}Xe	1.3×10^3	2.5×10^3	4.9×10^3	1.15×10^4
^{135}Xe	1.15×10^4	1.13×10^4	4.31×10^4	4.07×10^4
^{137}Xe	---	---	0	0
^{138}Xe	1.4×10^3	7×10^3	7.4×10^3	NM++
Total activity	3.36×10^4	3.42×10^4	1.24×10^5	1.26×10^5

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* Beck, H. et al., U. S. Atomic Energy Commission, personal communication, July 1972 and H. Beck, April 16, 1973.

** Based on delay line time of 72 min and release rate of 4.46×10^4 cc/s and stack flow rate of 7.79×10^1 m^3/s.

+ Based on delay line time of 75 min and release rate of 5.33×10^4 cc/s and stack flow rate of 7.79×10^1 m^3/s.

++ Assumed to be 7.4×10^3 µCi/s for total radioactivity calculation.

Note: NM - not measured.

Appendix E.1

Radionuclide Concentrations Measured in Aquatic Samples by the Station Operator

Analyses	Jan.-June 1970	July-Dec. 1970	Jan.-May 1971	June-Nov. 1971	Dec.-May 1971-2	June-Nov. 1972	Dec.-May 1972-3	June-Nov. 1973
				Surface Water, pCi/l				
No. samples	NR**	NR	NR	31	30	35	30	35
Gross α (S)*	NR	NR	NR	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Gross α (D)*	NR	NR	NR	< 0.3	0.53	< 0.3	0.27	< 0.3
Gross β (S)	NR	NR	NR	1.9	1.7	0.51	0.66	< 1.4
Gross β (D)	NR	NR	NR	3.8	3.7	2.0	1.6	< 2.1
^{40}K	NR	NR	NR	320	296	270	257	191
^{90}Sr	NR	NR	NR	0.58	0.63	0.36	0.46	0.70
U	NR	NR	NR	0.039	0.040	0.023	0.025	< 0.02
^{228}Ra	NR	NR	NR	1.6	1.1	1.1	0.97	0.93

Nuclides not detected were ^{3}H (< 1000), ^{58}Co (< 7.0), ^{60}Co (< 7.0), ^{65}Zn (< 9.0), ^{131}I (< 6.0), ^{137}Cs (< 7.0), ^{226}Ra (< 0.2).

				Silt, pCi/g				
No. of samples	NR	NR	NR	6	10	15	15	13
Gross α	NR	NR	NR	1.5	3.1	1.1	1.3	< 2.0
Gross β	NR	NR	NR	10	31	11	8.7	21
				Clams, pCi/g				
No. of samples	NR	24	21	6	6	9	6	9
Gross α	< 0.1-1.2	0.1-0.27	< 0.1	0.12	< 0.1	< 0.1	< 0.1	< 0.1
Gross β	< 0.1-1.7	0.4-2.3	1.3	0.9	1.1	1.1	1.2	1.2
^{40}K	2.3-3.2	1.7-4.5	3.5	2.9	3.4	3.6	3.0	< 1.2
^{65}Zn	< 0.12	< 0.1-0.25	0.15	0.09	0.11	< 0.09	< 0.09	< 0.09
^{90}Sr	0.006	< 0.001-0.011	0.008	0.005	0.021	0.021	0.021	< 0.003
^{137}Cs	< 0.009	< 0.07-0.15	0.10	0.12	< 0.07	0.09	0.10	0.08

Nuclides not detected were ^{58}Co (< 0.07), ^{60}Co (< 0.07), ^{131}I (< 0.06).

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* S - suspended solids; D - dissolved

**NR - not reported

Notes:
1. Data reported by station operator from June-Nov. and Dec.-May due to one month delay for sample analysis and reporting.(5)
2. Data for clams during 1970 were reported as a range rather than an average.

Appendix E.2

The Average Radionuclide Concentrations in Aquatic Samples Reported by the State of New Jersey (BRP)

Surface Water Samples, pCi/l*

Radionuclide	Forked River	Oyster Creek
^{3}H	< 1100	< 1100
^{54}Mn	< 0.14 (trace)	0.9
^{58}Co	< 0.13	0.3
^{60}Co	0.09	2.6
^{59}Fe	< 0.2	< 0.34 (trace)
^{90}Sr	0.3	0.3
^{134}Cs	< 0.2	4.0
^{137}Cs	0.4	6.3

*Water was continuously sampled from April to December 1972 in Oyster Creek and from January to April, 1973 in Forked River.

Sediment Samples, pCi/g-dry weight

	1971					1972		
Location	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{137}Cs	^{54}Mn	^{60}Co	^{137}Cs
Oyster Creek	2.0	0.6	9.5	0.4	0.5	0.8	4.8	0.4
Forked River	0.9	0.2	3.0	< 0.2	0.4	0.3	2.1	0.4
Barnegat Bay*	0.13	< 0.1	0.3	< 0.1	0.1	< 0.1	< 0.1	0.07

*Near mouth of Cedar Creek.

Macro-algae and Marine Grass Samples, pCi/kg-wet weight*

	1971			1972			
Species	^{54}Mn	^{58}Co	^{60}Co	^{54}Mn	^{58}Co	^{60}Co	^{103}Ru
G. verrucosa	1400	190 ± 160	1260	264	< 50	560	74
C. fragile	130	31 ± 23	150	70	< 20	120	25
U. lactuca	1420	250 ± 110	830	180	< 50	300	80
Z. marina	820	180 ± 95	630	150	< 40	580	< 50

*Radionuclides not detected and their minimum detectable levels were: ^{51}Cr (< 130), ^{59}Fe (< 75), ^{65}Zn (< 65), ^{106}Ru (< 260).

Shellfish Muscle Samples, pCi/kg-wet weight*

Analysis	1971	1972
No. samples	21	10
^{54}Mn	< 70 - 250 (70)**	< 60
^{58}Co	< 70 - 310 (75)	20 - 110 (47)
^{60}Co	< 30 - 470 (160)	60 - 220 (100)
^{65}Zn	< 100	< 100
^{90}Sr	3 - 90 (20)	1 - 5 (2)
^{131}I	< 40	NR+
^{134}Cs	< 40	< 40
^{137}Cs	< 40 - 180 (80)	20 - 44 (24)

* Samples collected in Barnegat Bay near Waretown and near the mouths of Oyster and Cedar Creeks.

**Average concentrations given in parentheses.

+NR - not reported.

Appendix E.3

Estimation of Airborne Radioactivity in the Environment

Oyster Creek uses the following diffusion equation for estimating annual average relative concentrations at distances downwind of its stack [see Oyster Creek Nuclear Generating Station - Environmental Report, Amend. No. 2 (1972)] :

$$\chi/Q_{ij} = \frac{\sum_i \sum_j f_{ij}}{\sqrt{2\pi}\;\theta\; x\; \sigma_{z_{ij}}\; \bar{u}_{ij}} \exp\left(-H_j^2/2\sigma_{z_{ij}}^2\right)$$

where:

χ/Q_{ij} = average relative concentration for the ith stability condition and the jth wind speed class, s/m^3 (χ represents the radionuclide concentration, in μCi/m^3; Q, the stack emission rate, μCi/s)

f_{ij} = fraction of time the wind direction occurs in the i, j condition

θ = sector angle in radians (22.5 degrees)

x = receptor distance downwind, m

$\sigma_{z_{ij}}$ = vertical plume standard deviation for the i, j condition, m

$\bar{u}_{ij}$ = average wind speed at stack height, m/s

H_j = effective stack height (112 m plus plume rise) for j wind speed, m

The station Environmental Report provides annual average relative concentrations calculated for 16 22.5-degree sectors at 10 incremental distances to 80 km. Values of σ_z were obtained from Watson and Gamertsfelder. Stack plume rise was calculated by the Holland-Moses method. The meteorological data were collected from February 1966 to February 1967, after a 122-m instrumented tower was erected 390 m west of the stack in February 1966. (The AEC Final Environmental Statement indicates that much of the meteorological data collected up to 1974 are of doubtful accuracy and notes that an improved program is being implemented. During the EPA study, misadjustments of some wind sensors, temperature indicators and chart recorders were detected by weather balloon and other observations.)

Average annual relative concentration values for various sector midpoint distances calculated by Oyster Creek staff are as follows:

Characteristic	Location	Annual average χ/Q, s/m^3
Highest concentration	2.4 km N (of stack)	6.02×10^{-9}
Approximate fenceline	0.8 km N	4.24×10^{-9}
Nearby population	2.4 km ESE	5.45×10^{-9}
Nearby population	2.4 km NNE	3.86×10^{-9}
Waretown, NJ	2.4 km SSE	3.43×10^{-9}
Fishing in discharge canal	0.8 km ESE	4.04×10^{-9}

The annual average stack release rate (Q) used for the station calculations was 25,000 μCi/s for a 365-d year. The station operator indicates that the highest average concentration occurs in the city of Forked River. Dose at the north exclusion fence is lower than in Forked River due to release from a tall stack. Annual dose to the closest resident (1.3 km NNE of the stack) is computed by the station operator to be 4.6 mrem after applying shielding and occupancy factors.

The AEC Final Environmental Statement indicates that the nearest residence is located about 1.1 km N of the stack, where χ/Q is 1.6×10^{-9} s/m^3. The total body dose due to air submersion at that location is 0.31 mrem/yr. Fishermen spending 700 hrs/yr at the highway bridge over the discharge canal receive an estimated total body dose of 0.20 mrem.

Appendix E.4

Atmospheric Dispersion and Plume Rise Estimates for Short-term Air Sampling

Concentrations of stack effluents at ground level on the plume centerline at various downwind distances during the test described in Section 6, were estimated by:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\{-\tfrac{1}{2} (\frac{H}{\sigma_z})^2\}$$

where:

χ = ground-level centerline concentration, μCi/m^3

Q = source release rate, μCi/s

σ_y = crosswind plume standard deviation, m

σ_z = vertical plume standard deviation, m

u = average wind speed, m/s

H = effective stack height (112 + Δh), m

Plume rise (Δh), the height of the plume centerline above the stack height, was calculated by the methods of Briggs. Stack parameters for the computations were effluent temperature of 305°K, velocity of 16 m/s, exit diameter of 2.5 m and volume flow of 78 m^3/s. The Meteorology Laboratory, EPA, provided calculations for various ambient air temperatures, wind speeds and atmospheric stabilities.

Parameters used to estimate dispersion for air concentration measurements (see Table 6.2):

Test no.	u, m/s	σ_y, m	σ_z, m	Δ, m
1c	8.8	122	48	24
2b	8.7	108	43	17
4d	5.4	240	75	41
5a	7.6	145	85	15
5b	7.3	97	41	26

Appendix F.1

Relation of Airborne Radionuclide Concentration to Dose Rate

Radionuclide	Critical organ	Air concentration dose rate factors,(1) pCi/cc : rem/yr
	Gases	
^{3}H (HTO)	Total body (In)(2)	2/5 = 0.4
(HT)	Skin (Sub)(3)	400/30 = 13
^{14}C (CO$_2$)	Fat (In)	1/5 = 0.2
	Total body (In)	2/5 = 0.4
^{13}N	Total body (Sub)	0.43/5(4) = 0.09
^{85m}Kr	Total body (Sub)	1/5 = 0.2
^{85}Kr	Total body (Sub)	3/5 = 0.6
^{87}Kr	Total body (Sub)	0.2/5 = 0.04
^{88}Kr	Total body (Sub)	0.28/5(4) = 0.06
^{131m}Xe	Total body (Sub)	4/5 = 0.8
^{133m}Xe	Total body (Sub)	2.8/5(4) = 0.6
^{133}Xe	Total body (Sub)	3/5 = 0.6
^{135}Xe	Total body (Sub)	1/5 = 0.2
other fission gases with half-lives < 2 hrs	Total body (Sub)	0.27/5(4) = 0.05
	Airborne particles and iodine by inhalation	
^{51}Cr	Lung (I)(5)	0.8/15 = 0.053
^{54}Mn	Lung (I)	0.01/15 = 0.00067
^{55}Fe	Spleen (S), Lung (I)	0.3/15 = 0.020
^{59}Fe	Lung (I)	0.02/15 = 0.0013
^{58}Co	Lung (I)	0.02/15 = 0.0013
^{60}Co	Lung (I)	0.003/15 = 0.00020
^{65}Zn	Lung (I)	0.02/15 = 0.0013
^{89}Sr	Bone (S)(6)	0.01/30 = 0.00033
	Lung (I)	0.01/15 = 0.00067
^{90}Sr	Bone (S)	0.0001/30 = 0.0000033
	Total body (S)	0.0003/5 = 0.000060
^{99}Mo	Lung (I)	0.07/15 = 0.0047
^{131}I	Thyroid (S)	0.003/30 = 0.0001
^{133}I	Thyroid (S)	0.01/30 = 0.00033
^{135}I	Thyroid (S)	0.04/30 = 0.0013
^{134}Cs	Lung (I)	0.004/15 = 0.00027
^{136}Cs	Lung (I)	0.06/15 = 0.004
^{137}Cs	Lung (I)	0.005/15 = 0.00033
^{140}Ba	Lung (I)	0.01/15 = 0.00067
^{141}Ce	Lung (I)	0.05/15 = 0.0033
^{239}Np	GI(LLI) (I)	0.2/15 = 0.013

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1. ICRP, Report of Committee II on Permissible Dose for Internal Radiation, ICRP Publication 2, Pergamon Press, Oxford (1959). Concentrations based on 168-hour limits.
2. (In) = Inhalation
3. (Sub) = Submersion
4. Based on ICRP Publication 2, equation [illegible], divided by 4 for a 168-hour week.

$$(MPC)_a = \frac{[illegible]}{(\Sigma E)} \times [illegible]$$

where (ΣE), the total effective energy per disintegration (β, e, β^+, e^-, x-rays), has the values:

^{13}N = [illegible] MeV
^{88}Kr = [illegible] MeV
^{133m}Xe = [illegible] MeV

Short-lived nuclides

($T_{1/2}$ < 2 hrs) [illegible] MeV (based on ^{88}Kr, the radionuclide of the highest disintegration energy with a half life less than 2 hours).

5. (I) = Insoluble
6. (S) = Soluble

Appendix F.2

Relation of Daily Radionuclide Intake in Water to Dose Rate

Radionuclide	Critical organ	Daily intake-dose rate factors,$^{(1)}$ pCi/day ÷ mrem/yr	Radionuclide	Critical organ	Daily intake-dose rate factors,$^{(1)}$ pCi/day ÷ mrem/yr
^{3}H	Total body	22,000	^{99m}Tc	GI(LLI)	8,800
^{14}C	Total body	4,400	^{103}Ru	GI(LLI)	120
^{24}Na	GI(LLI)	290	^{106}Ru	GI(LLI)	15
^{32}P	Bone	15	^{105}Rh	GI(LLI)	150
	Total body	400	^{110m}Ag	GI(LLI)	40
	GI(LLI)	130	^{124}Sb	GI(LLI)	30
^{51}Cr	GI(LLI)	2,900	^{131}I	Thyroid	1.5$^{(3)}$
^{54}Mn	GI(LLI)	150	^{133}I	Thyroid	5.1$^{(3)}$
^{55}Fe	Spleen	1,170	^{135}I	Thyroid	15$^{(3)}$
^{59}Fe	GI(LLI)	90	^{134}Cs	Total body	40
	Spleen	150	^{136}Cs	Total body	400
^{57}Co	GI(LLI)	730	^{137}Cs	Total body	90
^{58}Co	GI(LLI)	150	^{140}Ba	GI(LLI)	40
^{60}Co	GI(LLI)	70	^{141}Ce	GI(LLI)	130
^{64}Cu	GI(LLI)	440	^{144}Ce	GI(LLI)	15
^{65}Zn	Total body	440	^{210}Po	Spleen	1.0
^{76}As	GI(LLI)	30		Kidney	1.2
^{89}Sr	Bone	7.3		Liver	4.4
^{90}Sr	Bone	0.30$^{(2)}$		Bone	7.3
^{91}Sr	GI(LLI)	100		Total body	30
^{95}Zr	GI(LLI)	90		GI(LLI)	40
^{95}Nb	GI(LLI)	150	^{239}Np	GI(LLI)	150
^{99}Mo	GI(LLI)	290			

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1) ICRP Report of Committee 2 on Permissible Dose for Internal Radiation, ICRP Publication 2, Pergamon Press, Oxford (1959); Intake, based on 168 hour concentration limits, assumed to persist for 50 years or until equilibrium is reached in the body.

2) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6, Pergamon Press, Oxford (1964).

3) To calculate a child's thyroid dose, divide this factor by 10.